ROAD BRIDGES IN GREAT BRITAIN

ILLUSTRATED DESCRIPTIONS, WITH MANY WORKING DRAWINGS OF COMPLETE DESIGNS AND DETAILS, PROGRESS PHOTOGRAPHS, AND NOTES ON CONSTRUCTION METHODS, RELATING TO 96 REINFORCED CONCRETE BRIDGES OF VARIOUS TYPES AND SPANS.

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PUBLISHERS' NOTES

The contents of this book have already been published in the monthly journal "Concrete and Constructional Engineering," and are reprinted in book form because they comprise the most comprehensive guide so far published to modern methods in the design and construction of reinforced concrete bridges in Great Britain. The Ministry of Transport's Standard Loading, on which these designs are based, is given on pages 169-70.

Our thanks are due to a large number of engineers and surveyors to local authorities and consulting engineers who have so kindly collaborated in the preparation of these descriptions.

June, 1939. THE PUBLISHERS.

Advantage has been taken in reprinting this book to give a more extended description of Waterloo Bridge, London, which has now been completed. The reader is reminded that these bridges had been recently completed, or were designed or in course of construction, in the year 1939.

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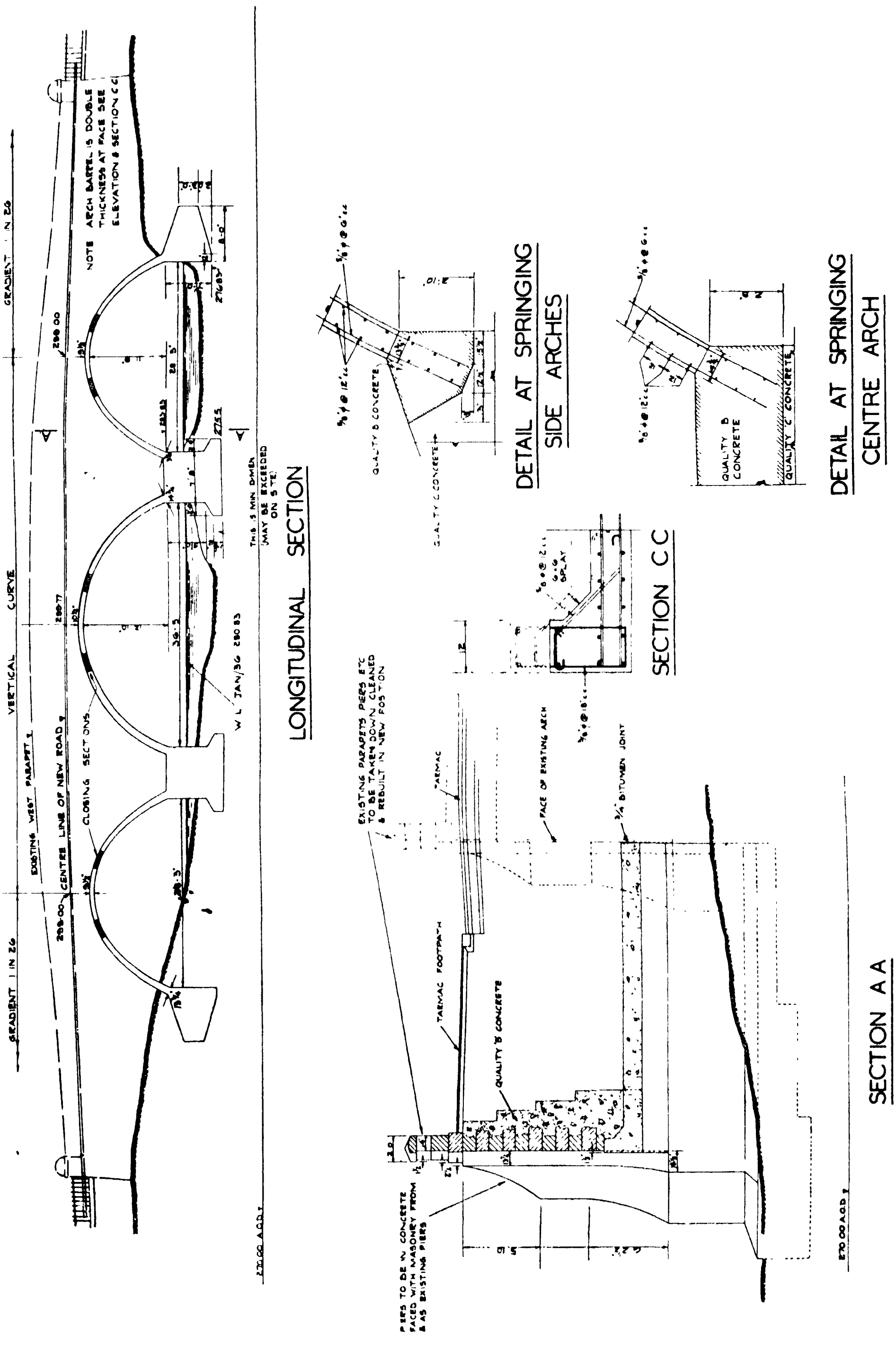
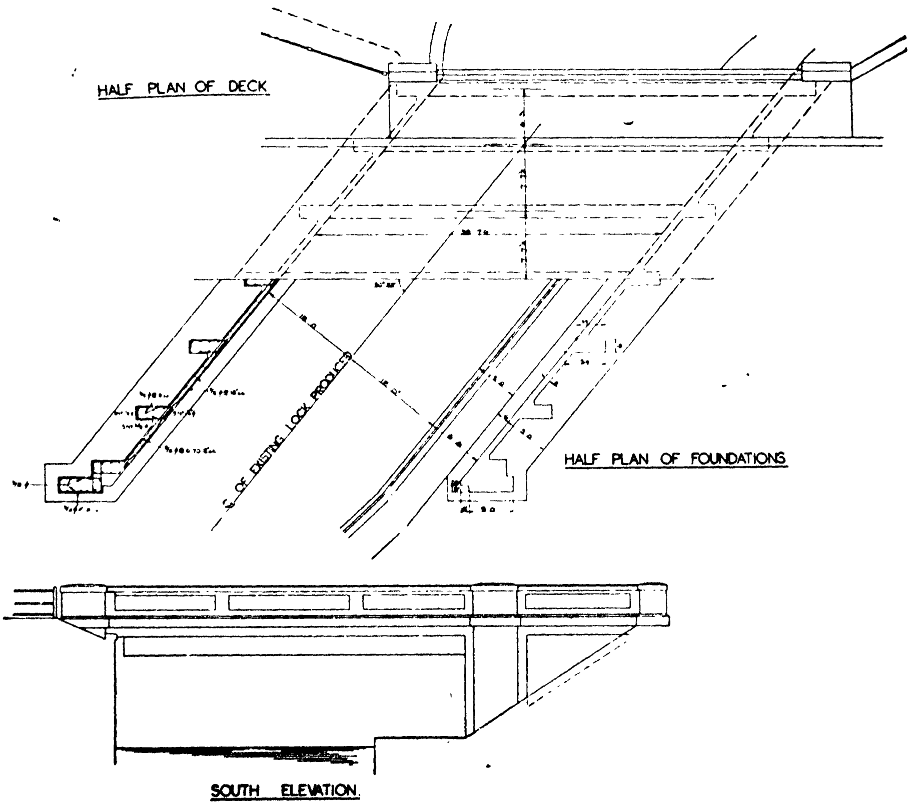


Fig. 9.—Silsden River Bridge.

FIG. 10.—ANCHOR CANAL BRIDGE: OLD BRIDGE AND COFFERDAM FOR NEW ABUTMENT.



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ROAD BRIDGES IN GREAT BRITAIN

THE contents of this book show that almost any type of bridge may be built in reinforced concrete. Up to the present time all types except the true Vierendeel girder bridge have been constructed in Great Britain, and several are of noteworthy dimensions. Much progress has been made since 1902 when, it is believed, the first reinforced concrete bridge in England was built at Satterthwaite, Lancashire. This was a single span of 43 ft. 7 in. The largest bridge is at Berwick-on-Tweed and was opened to traffic in 1928. It is 1405 ft. long and contains arch spans of 167 ft., 248 ft., 285 ft., and 361 ft. 6 in. The width is 46 ft.

The authority responsible for road bridge design in Great Britain is the Ministry of Transport which has issued a standard of superimposed loading and specified the permissible stresses. For tension in the reinforcement and flexural compression in concrete in the proportions of 90 lb. of cement to 2 cu. ft. of sand and 4 cu. ft. of coarse aggregate these are 16,000 lb. per square inch and 750 lb. per square inch respectively. The modular ratio is assumed to be 15.

With the exception of some bridges composed of pre-cast girders, continuous spans—with or without suspended intermediate portions—and arches designed in accordance with the elastic theory are universal in modern practice. Each type has advantages in ensuring uniform strength at all sections and can be trusted if the stability assumed in the piers and abutments is realized in practice. The elastic theory is not exact, any more than any other theory is, but it has been shown to be sufficiently in accordance with the results of tests to be used in design [see "Tests of Rigid Frame Bridges," CONCRETE AND CONSTRUCTIONAL ENGINEERING, October, 1938 (experiments on 48-ft. spans.)]

The ease with which continuity can be obtained in reinforced concrete structures is one of the great advantages of the material. Whether at the middle of the span or above the supports construction is the same in principle, and even at the knee-joints in portal frames there are no complications due to special radial stiffeners provided to prevent buckling. In Great Britain there are many rigid-frame bridges which show how continuity in the structure produces an efficient distribution of the concrete and reinforcement among the different members. Other advantages of this type are that lower embankments are required when the depth of construction is limited and the clearance below the bridge remains unchanged, and that excavation and concrete are saved because very heavy abutments are not required in order to obtain the necessary fixity. Cellular construction of frames is a modern development illustrated in several designs, and another recent innovation is the balancing or counterweight slab of reinforced concrete which is built behind the abutments.

In designing brick and masonry arches in the past the avoidance of skew spans was almost always considered to be an essential feature of a good design, and little, if any, consideration was given to an unobstructed view along the approaches to the bridge and the bridge itself. One reason for this policy was that the work in the drawing office was increased by the complications in skew-arch design due to the need for drawing the bed joints and side joints of the stones on the development of the soffit. Another, and more pertinent, reason was the additional cost of dressing

the stones to the correct shapes and laying the courses accurately. At the present time it is rightly considered that the presence of bends at bridge approaches is seldom justified even if it enables a square span to be used. Moreover modern arches, of which many are illustrated, are generally monolithic and, so far as construction is concerned, differ little whether they are square or skew spans. It is in design that the differences still exist and, even if a simple but exact theory of monolithic skew-arch design is not yet available, there are approximate methods which take account of the fact that arches of this class are three-dimensional so far as stress determination is concerned and should not be analysed as if they were strips parallel to one plane.

The very great width of by-pass roads has had its effect on the available choice of bridge types. Some of these roads are 120 ft. wide between the fences and accommodate 22-ft. dual carriageways separated by a central verge, as well as cycle tracks and footpaths, whereas the span of the bridge may be only 30 ft. or less. In these cases, as in all bridges where the total width of carriageway and footpaths is not quite small, the through-girder type is uneconomical because the deck spans between the main girders and the accumulated dead and live loads on cross girders 40 ft. to 50 ft. long would cause these to be very heavy. These heavy loads must therefore be carried by the cross girders in the first place and carried a second time by the main girders, whereas if these secondary girders are replaced by longitudinal girders arranged parallel to the direction of the span they are lighter and transmit the loads directly to the abutments.

Another objection to the use of through main girders is that if they are placed outside the footpaths their spans are very long, and if two are in the position of the kerbs and a third is in the central verge their projection above the level of the carriageway is unsightly.

Bowstring girders—as distinct from the fish-bellied type—are, of course, used in through bridges, but only where the road is narrow and generally with the footpaths cantilevered outside the girders. Although a parabolic outline is theoretically advantageous for the upper boom, there is little loss of efficiency and considerable gain in appearance if the curved member is segmental. They are seldom used for spans of less than 100 ft., and a span of 150 ft. or so is necessary if they are to be braced between the curved members, since the rise-span ratio is generally 1 to 5 and a minimum clearance of 16 ft. 6 in. is required above the deck level. If direct bracing cannot be inserted, its function is fulfilled by the hangers which transfer the stresses to the floor and are usually wide and thin.

BRIDGES IN THE WEST RIDING

SEVERAL concrete bridges have been recently completed or are in process of construction in the West Riding. Amongst these structures are Limeworks bridge and Stubbs culvert on the Wakefield–Doncaster road, Kirksmeaton bridge, Silsden bridge, Anchor canal bridge and Long Preston bridge on the Keighley–Kendal county road, and Smithies bridge on the Leeds–Preston trunk road. The designs for all the structures have been prepared in the bridge office of the West Riding Surveyor, Mr. H. R. Hepworth, M.Inst.C.E., F.S.I.

LIMEWORKS RAILWAY BRIDGE.

Large Pre-cast Beams.

These works, now completed, are part of an extensive reconstruction scheme on arch structure carrying the road over a goods branch of the L.N.E.R. Leeds to Doncaster and London line.

The widening was carried out in reinforced concrete using pre-cast beams spanning 24 ft. 11 in. clear on the skew between cantilevers off strutted counterfort abutment walls. The structure provides for laying additional track, the square span being 26 ft. 6 in. and the skew span 34 ft. 5 in. between abutments. The beams are inverted trough-shape units 29 ft. 5 in. long, 5 ft. 3 in. wide and 2 ft. deep. They are designed as L-beams, the stems being 9 in. by 16 in. connected with an 8-in. slab and four cross-beams. The two centre cross-beams were designed and positioned to provide the necessary strength and balance for lifting.

The railway at this point runs through

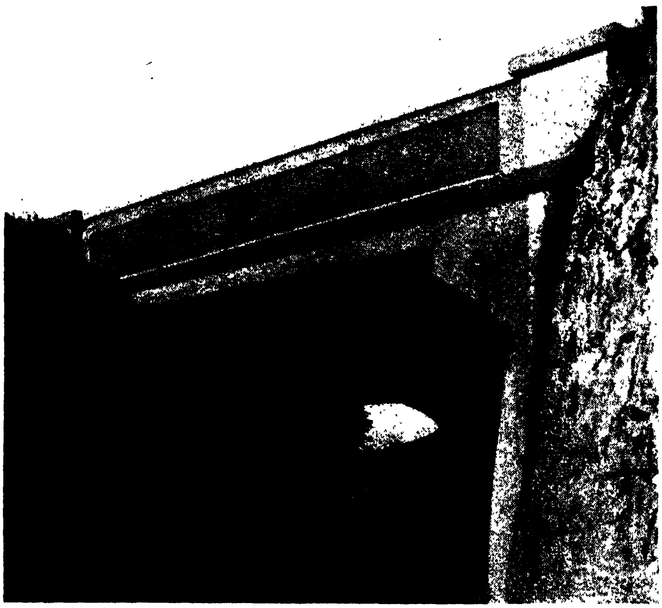
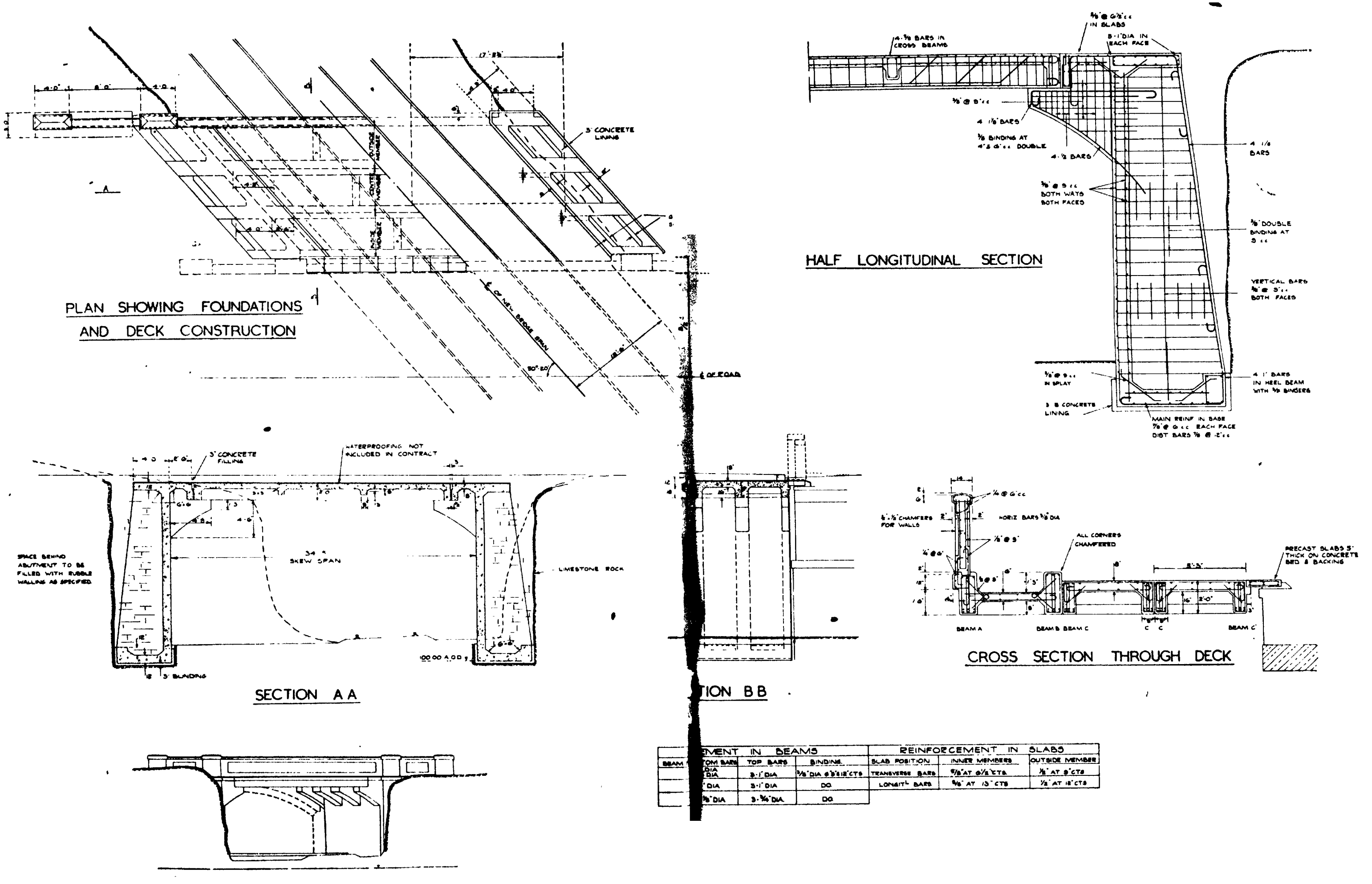


FIG. 1.—LIMEWORKS RAILWAY BRIDGE.

the Redhouse and Crofton county road at Hampole, seven miles north of Doncaster.

The Limeworks bridge (*Figs.* 1 and 2) scheme included a widening of approximately 16 ft. on each side, i.e. to 60 ft. between parapets, of the existing brick

a deep rock cutting and the abutments are in recesses cut in the solid limestone. The spaces behind were built up with broken rock in the manner of dry walling, and back pressure was therefore neglected in the design. The overturning couple



[illegible]MENT IN BEAMS				REINFORCEMENT IN SLABS		
BEAM	[illegible]TOM BARS	TOP BARS	BINDING	SLAB POSITION	INNER MEMBERS	OUTSIDE MEMBER
	[illegible] DIA	3-1" DIA	3/8" DIA @ 6" & 12" CTS	TRANSVERSE BARS	5/8" AT 6½" CTS	½" AT 9" CTS
	[illegible]" DIA	3-1" DIA	DO	LONGITL BARS	3/8" AT 13" CTS	½" AT 18" CTS
	[illegible]/8" DIA	3-3/4" DIA	DO			

Fig. 2.—Limew[illegible]way Bridge.

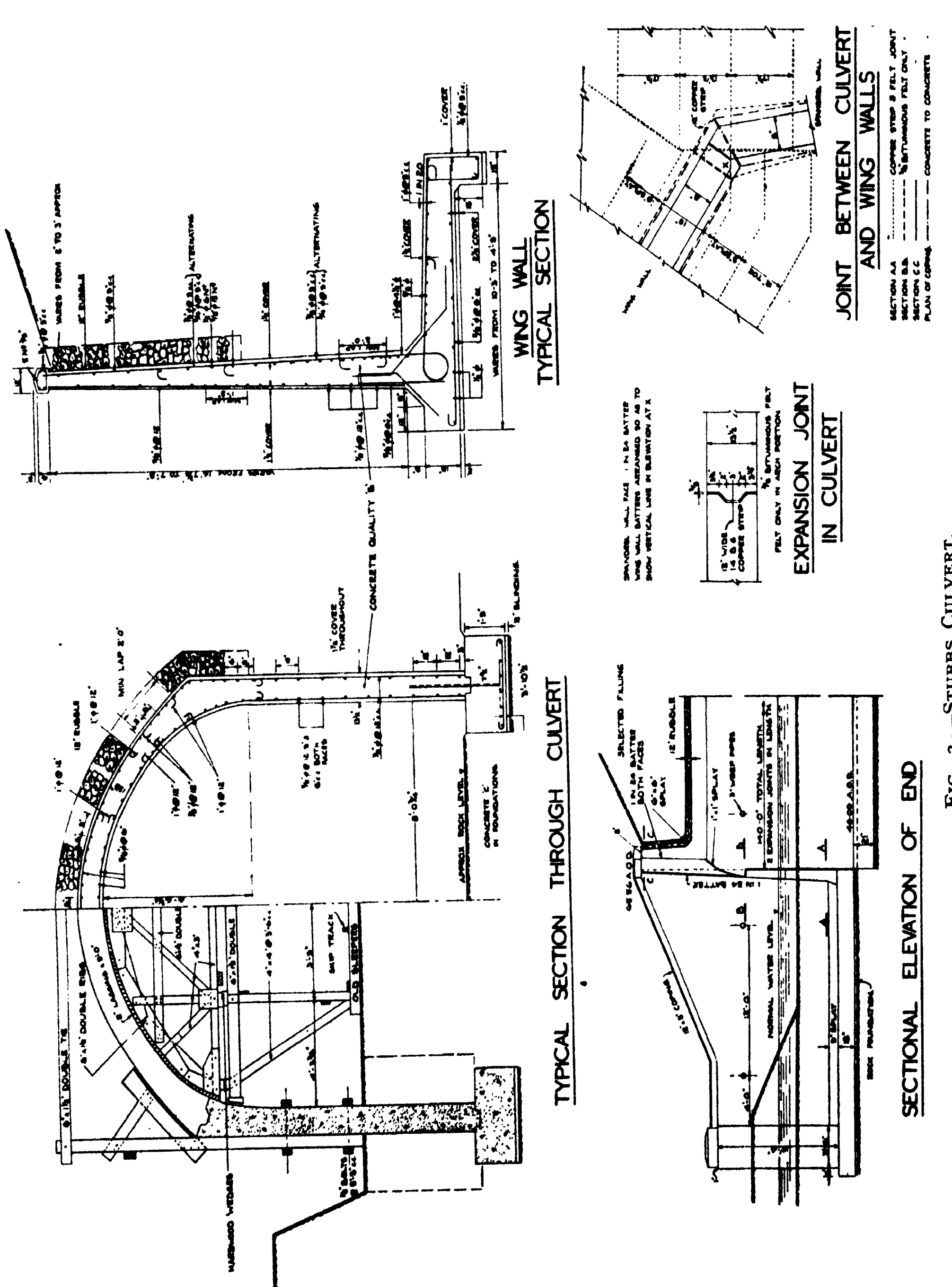


FIG. 3.—STUBBS CULVERT.

set up by the cantilevers is resisted by the strutting action of the pre-cast members, and the abutment foundation is in trenches cut in the solid rock, the ground pressure set up being only 3 tons per square foot. Owing to the large skew the abutments are stiffened against horizontal torsion from the cantilevers by the top horizontal beam. The total weight of each inner pre-cast member is approximately 10½ tons, and that of each outer member approximately 12 tons.

The very limited working space in the cutting and the fact that the crane available was a 36-ton railway steam crane made it necessary for the members to be cast partly under the old bridge in two sets of three on top of each other, and in such a position that the crane could jib under to lift the members first on to a truck and then from the truck into their respective positions. The line was closed for eight hours on two Sundays for this work. The only difficulty encountered was that of manœuvring the crane in the narrow cutting.

The bridge has a bush-hammered finish, the aggregate being pink Leicester granite. The concrete mix was 100 lb.: 2 : 4 throughout (see note, p. 18, on concrete mixes), and the design loads were to the Ministry of Transport standard requirements. The total cost of the scheme was £1,508, or approximately £1·37 per square foot of deck exclusive of roadwork. The contractors were the Ebor Construction Co., Ltd.

STUBBS CULVERT.

Details of Centering.

Stubbs culvert (*Figs.* 3 to 6), together with another railway bridge in steel over the L.N.E.R. main line, is on a new diversion of the road about one mile to the north of Limeworks bridge. A short portion of the new road is to be carried on an embankment 30 ft. high, under which Stubbs Beck has to be carried in a culvert.

This structure is a reinforced concrete hinged frame with a parabolic roof. It is 140 ft. long, 16 ft. 1½ in. clear span, and 13½ in. thick generally except at the haunches. The frame measures approximately 12 ft. from the hinges to the haunches and the rise of the arch axis is 4 ft. 7½ in. It gives a clear water area of 150 square feet; this area was found to be necessary from past flood records.

FIG. 4.—STUBBS CULVERT: SIDE WALLS COMPLETED AND ROOF STARTED.

There are four cantilever wing walls each 24 ft. long and varying from 11 ft. 2 in. to 18 ft. in height. They are all set at 45 deg. to the line of the road, and the centre line of the culvert is at an angle of 78 deg. with the road.

The foundation of the frame was cut into the limestone rock to provide a good lateral key. The maximum pressure on

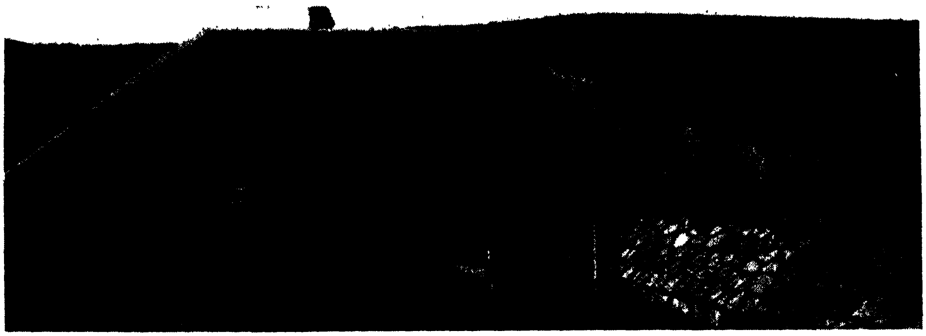


FIG. 5.—STUBBS CULVERT: DOWNSTREAM END.

the bed is approximately $4\frac{1}{2}$ tons per square foot for the culvert, and 2 tons per square foot for the wing walls. The excavation being in good clay, although deep and close to the existing stream on the one side and a partly-made embankment on the other, presented no difficulty other than from a plentiful supply of water which was encountered in a gravelly stratum between the clay and the rock surface.

The wall shuttering was brought up in 3-ft. lifts, and the arch centres were arranged in units 12 ft. long with three centres to each unit. The complete upper unit was raised and lowered by jacks on to a movable platform built on a jubilee track inside the culvert which could be moved into position very quickly; three of these units were made to speed up the work. The jubilee track was used previously in the excavation and concreting of the walls.

The culvert was constructed by direct labour at a cost of £3,500, or approximately £1·36 per square foot of the pro-

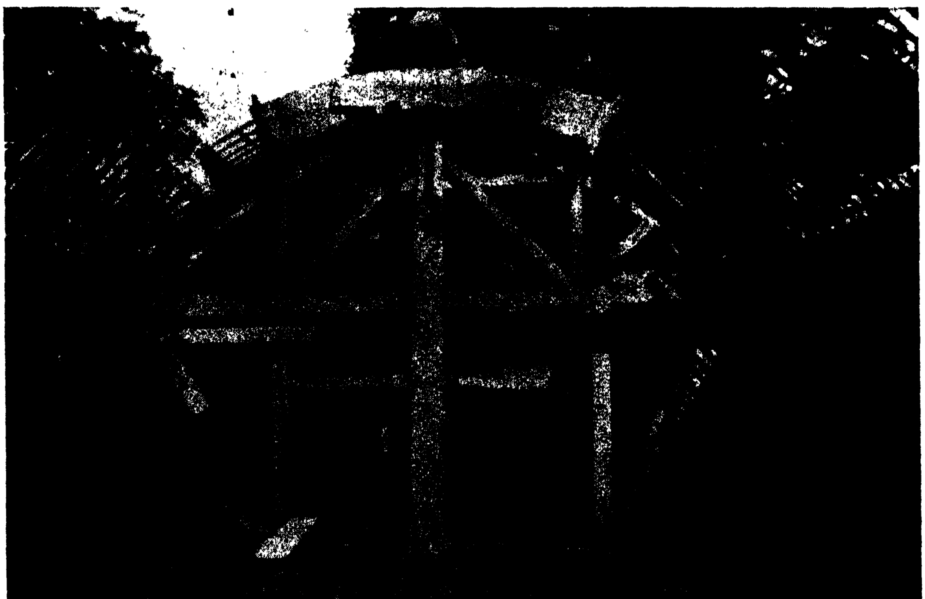


FIG. 6.—STUBBS CULVERT: CENTERING FOR ROOF.

jected roof area. These figures include the wing walls and the cutting of the new stream diversion but do not include any filling over the structure.

KIRKSMEATON BRIDGE.

Superelevated Deck.

The road at Kirksmeaton formerly crossed the river Went by a ford which was subject to severe flooding, and as the road was often impassable at these times a bridge was constructed west of the ford with re-aligned approaches.

with carborundum blocks except in the panels of the parapet which were treated with a cement-retarding liquid. The cost of this bridge was £1,186 (slightly less than £1 per square foot of area spanned), and the contractors were Messrs. Fred Whitaker & Co., Ltd.

The finished bridge is shown in *Fig.* 7.

SILSDEN RIVER BRIDGE.

Widening a Masonry Arch.

The existing masonry structure over the river Aire was built in 1804 at a

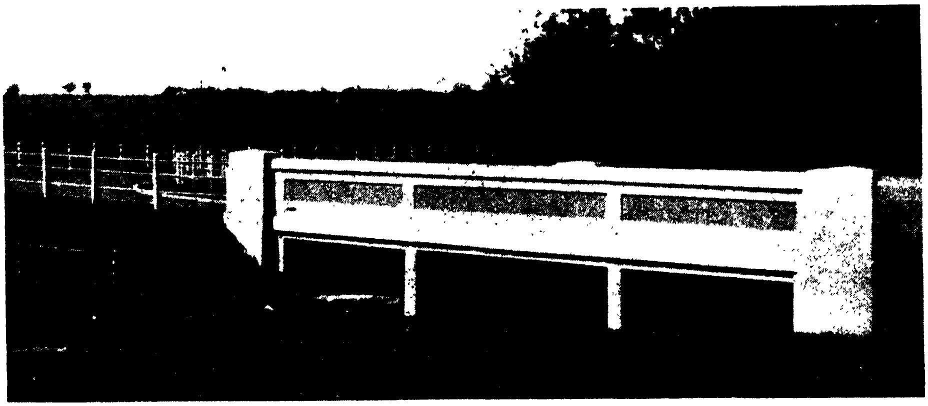


FIG. 7.—KIRKSMEATON BRIDGE.

The bridge (*Figs.* 7 and 8) consists of a simple slab continuous over three spans with a soffit approximately 12 in. above maximum flood level. The spans are arranged in the ratio of 1 : 1·3 : 1, giving support and span moments approximately equal and a simple system of straight bars in the reinforcement (*Fig.* 8). The abutments are 18 in. thick designed as propped by the deck, and these and the 12-in. piers have ⅝-in. bars at 9-in. centres both ways in each face.

An ideal superelevation could not easily be obtained over the curved approach on the south and, due to the close proximity of the curve to the bridge and the shortness of the curve, the transition took place partly over the bridge but it was not found difficult to warp the deck to provide the necessary falls and gradients in the road surface.

The concrete mix was 100 lb. : 2 cub. ft. : 4 cub. ft. (quartzite aggregate). The surface finish was obtained by rubbing

cost of £3,600, and consists of three barrel arches 22 ft. wide between parapets. It is to be widened to 45 ft. by the construction of reinforced concrete arches on one side with approximately the same clear spans and rises. The whole of the masonry facework in the spandrels, pilasters, and cutwaters is to be taken down on the widened side and re-used in the new elevation, the architectural features being repeated.

The existing arches are segmental but the shape for the widened portion has been chosen so that the axis follows the line of thrust of dead loading, and this has resulted in fairly slender sections being obtained due to the high rise-span ratio as shown in the table on page 10.

The design stresses used in the arch are 16,000 lb. per square inch in the steel and 800 lb. per square inch in the concrete, which was mixed in the proportions of 100 lb. : 2 cub. ft. : 4 cub. ft. The steel is arranged in four lengths

Arch	Span (ft. and in.)	Rise (ft. and in.)	Section (in.)		Reinforcement
			Springing	Crown	
Centre	36 5	12 10	14¾	10½	⅝-in. bars at 6-in. centres
Side	28 3	11 8	13¾	9½	⅝-in. bars at 6-in. centres

lapping just clear of the springing sections and at the closing sections about 4 feet on each side of the crown (see longitudinal section *Fig.* 9). To improve the appearance of the elevation, the barrel is made twice its designed thickness at the face (see section *CC*).

The existing piers are built on a timber raft supported by timber piles. In the widened portion reinforced concrete bored piles are being used. The contract is being carried out by Messrs. John Cooke & Son (Huddersfield), Ltd., and the François Cementation Co., Ltd., are sub-contractors for the piling.

ANCHOR CANAL BRIDGE.

Skew Span of 39 ft. 7 in.

The existing masonry arch bridge over the Leeds and Liverpool Canal on the Keighley–Kendal county road at Gargrave (*Fig.* 10) is of a type frequently found. It is 22 ft. wide and has a span

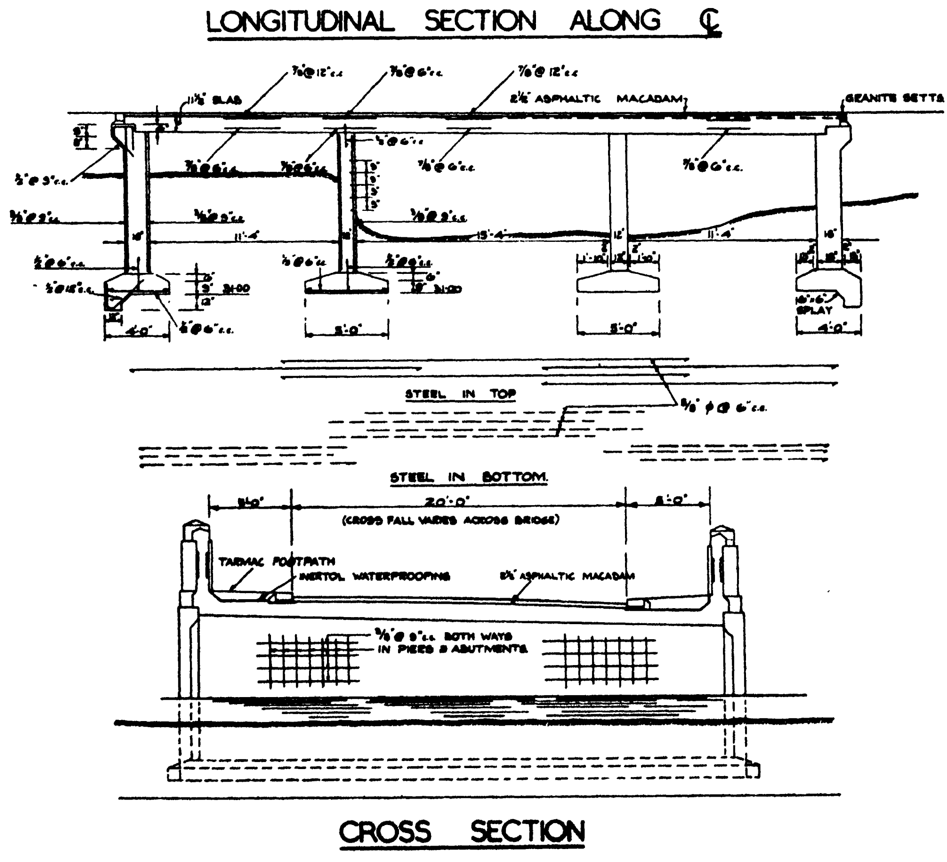


Fig. 8.—Kirksmeaton Bridge.

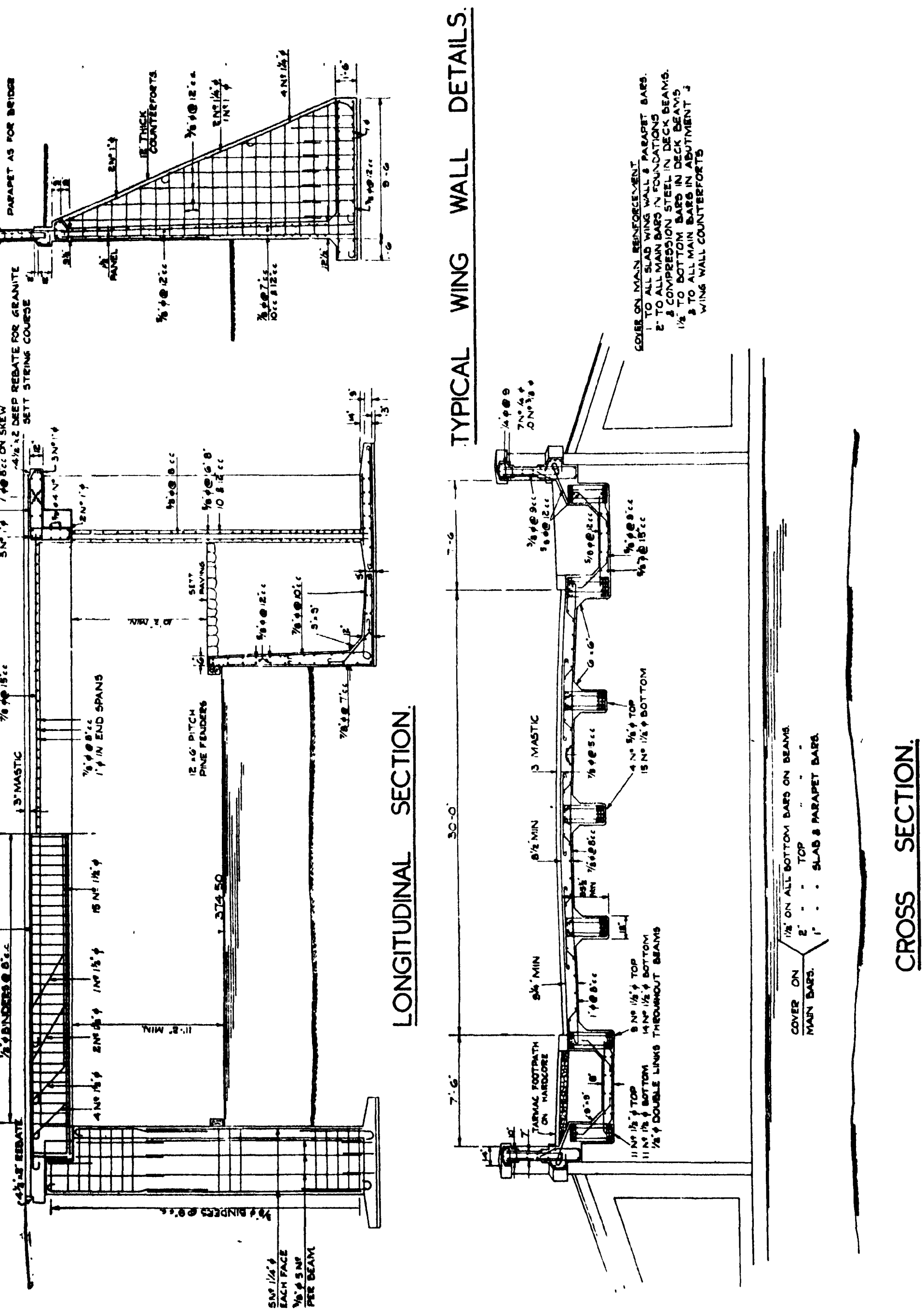


FIG. 12.—ANCHOR CANAL BRIDGE.

of 16 ft. square to the canal, and by reason of the formation of an S-bend in the road and a hump-back over the bridge the visibility is very poor. The improvement will comprise approximately 650 yd. of new road 60 ft. wide between fences, with a new reinforced concrete bridge to the north of the old bridge. The new structure provides for a waterway and headway during construction of 20 ft. and 9 ft. 6 in. respectively. The completed bridge will provide a waterway of 24 ft. in addition to a 6-ft. 6-in. wide towing path, and a headway of 10 ft. 6 in.

The bridge (*Figs.* 11 and 12) is a beam and slab type on strutted counterfort abutments. The square span is 30 ft. 6 in. with a skew span of 39 ft. $7\frac{1}{4}$ in. The main beams are 27 in. by 18 in. net at 7-ft. $7\frac{1}{2}$-in. centres supporting an $8\frac{1}{2}$-in.

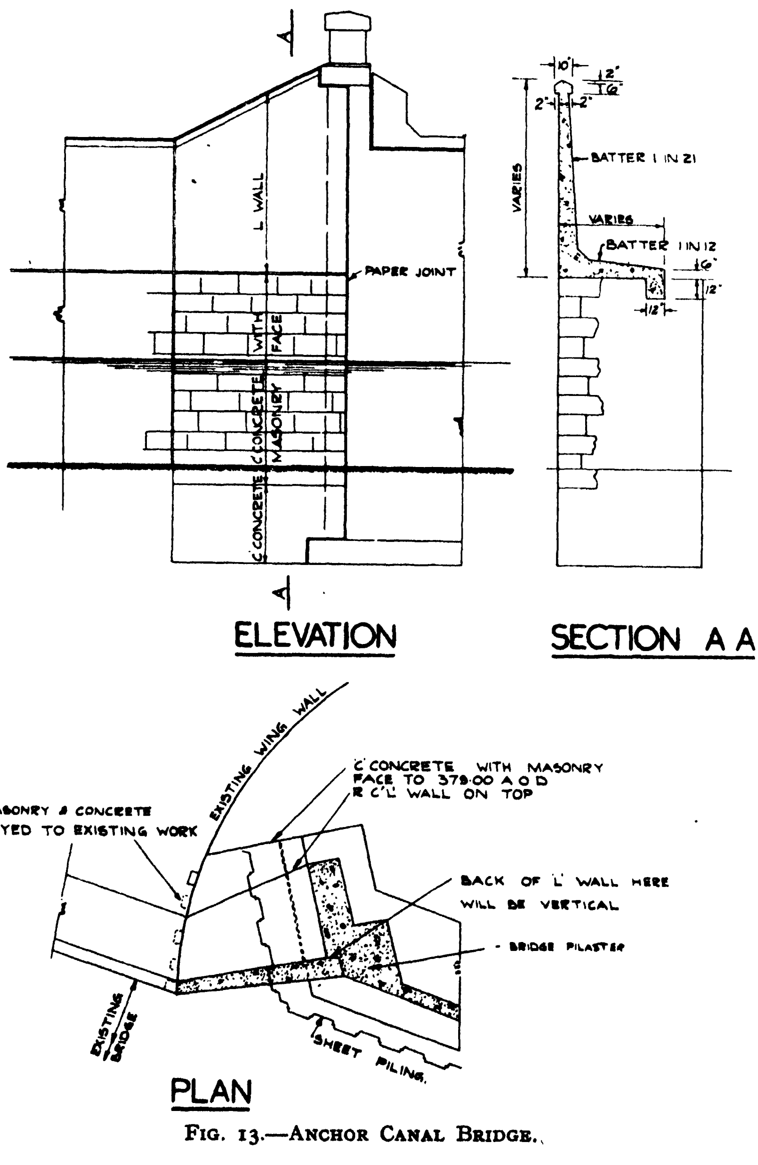


FIG. 13.—ANCHOR CANAL BRIDGE.

roadway slab laid to the falls and gradients of the roadway. The slab is dropped under the footpath to provide pipe ducts.

The 8-in. thick abutment walls span 10 ft. between 18-in. thick counterforts of an average depth of 46½ in. carried on a continuous reinforced concrete footing 14 in. to 9 in. thick. A very good gravel and clay foundation has been found.

The contract also includes the construction of approximately 110 ft. of reinforced concrete counterfort wing walls with an average height of 17 ft. and 250 ft. of reinforced concrete cantilever canal walls 11 ft. 6 in. high. The concrete mix for reinforced concrete is 100 lb. : 2 cub. ft. : 4 cub. ft. (pink Shap granite), and parts of the finished structure will be bush-hammered.

and brought up to just above water level. The existing bridge is to be taken down a little below springing level, and an L-type reinforced concrete wall built along the old abutments.

The estimated cost of the bridge is £2,490 (approximately £1 per square foot), and the wing and canal walls will cost £2,190 or about 8*s*. per square foot of wall. The whole contract, totalling £23,000, is being carried out by Messrs. Fred Whitaker & Co., Ltd.

LONG PRESTON BRIDGE.

Constructed in Two Portions.

This is one of several bridges to be reconstructed by the West Riding County Council on the Keighley–Kendal county

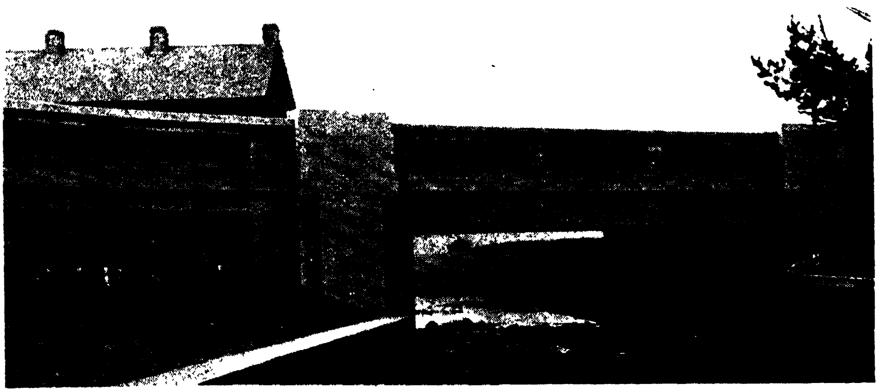


FIG. 14.—LONG PRESTON BRIDGE.

Before withdrawing the cofferdams, a stiff clay filling is being placed between the finished work and the dam in order to effect an efficient seal for the canal, the original clay lining having been broken by the driving of the piles. Existing masonry training walls and clearance requirements made it impossible to drive a cofferdam sufficiently large to permit the construction of the short wing walls between new and old structures at the same time as the bridge, so the dam was turned into the bank just clear of the old structure (see *Fig.* 13) and the abutment completed. The canal was then drained off for a period of twelve hours (at a cost of less than £5) and mass concrete with a masonry face placed along the line of the wing wall

road, which is the main route from the industrial West Riding to the Lake District. The bridge is at the junction of route A65 and the Gisburn road (A682). The old stone arch bridge was narrow and hump-backed, the south approach forming a right-angle bend, and the junction with route A682 was obscured by a block of cottages.

The new scheme involved the demolition of the old bridge and cottages, the widening and improvement of gradients of the three approaches, and the construction of the new bridge to a width between parapets varying from 64 ft. to 70 ft. Direction islands were placed on each approach with electrically-illuminated bollards operated by a Radiovisor unit to ensure greater safety at the junction.

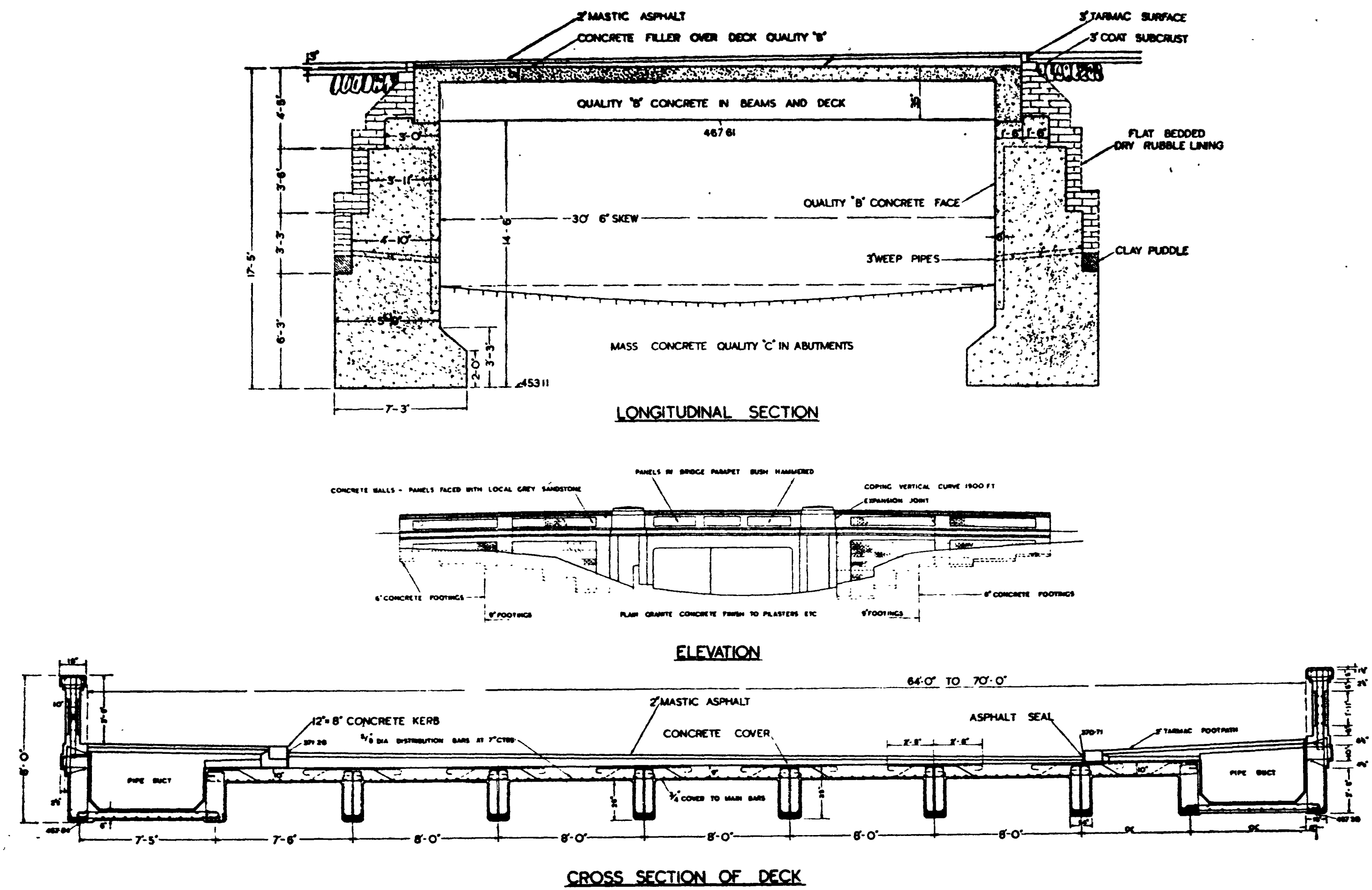


FIG. 15.—LONG PRESTON BRIDGE.

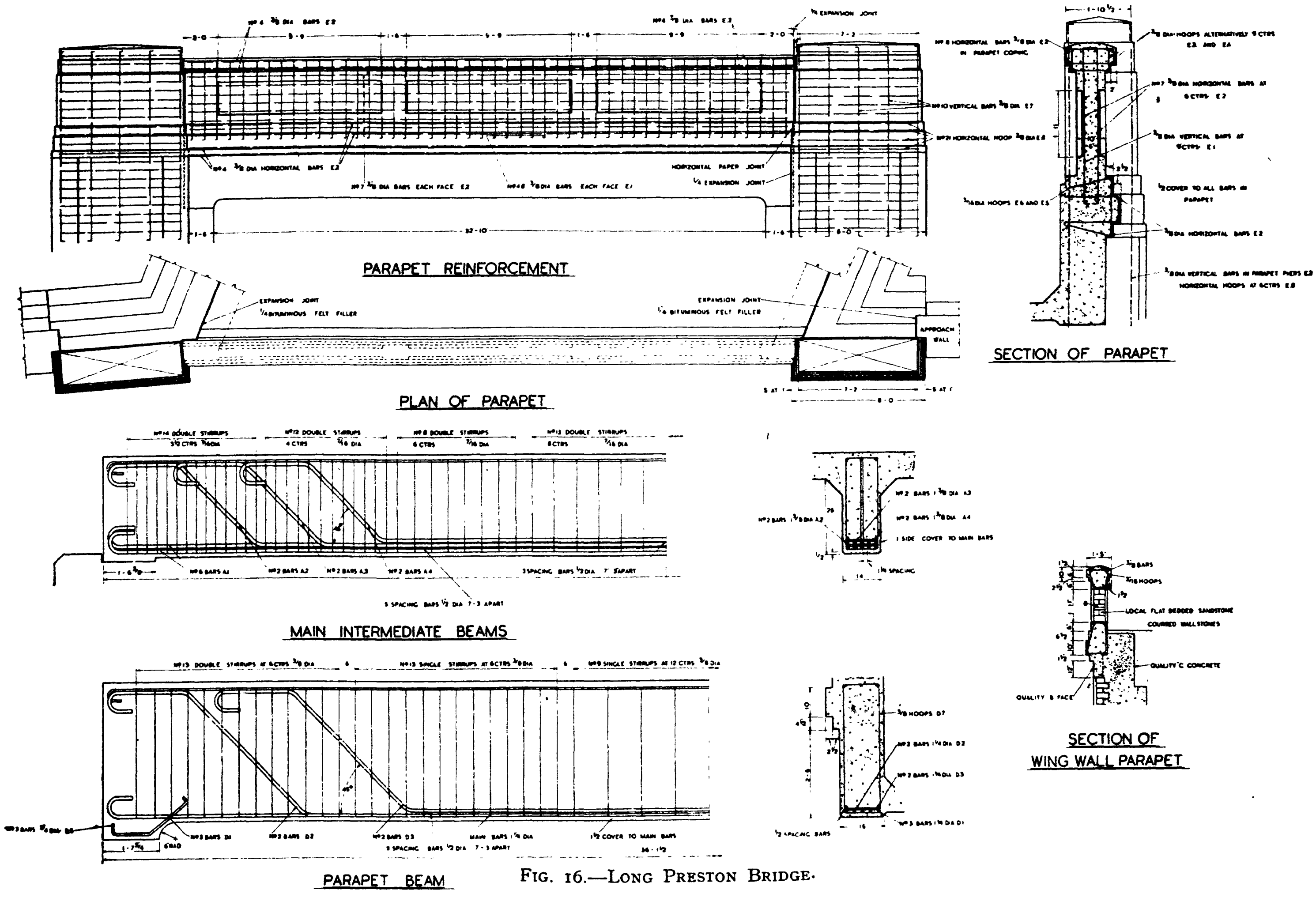


FIG. 16.—LONG PRESTON BRIDGE.

The new bridge has a square span of 30 ft. and a skew span of 32 ft. 10 in. upstream and 30 ft. 6 in. downstream. Although this is a reduction of waterway compared with that of the old structure, it is in excess of that afforded by bridges downstream which have readily coped with the highest known floods. The bridge is high up in the watershed, above any developed areas, and estimates made of the probable maximum run-off compared very reasonably with the highest floods. By reducing the span a shallower depth of construction could be adopted and the hump in the road entirely removed.

bars and seven 1¼-in. bars respectively with suitable ⅜-in. hoops for shear (*Fig.* 16). There are pipe ducts under the footpaths on both sides of the bridge, the floors being formed by a 6-in. doubly reinforced slab. The ducts and portions of the deck under the footpaths are waterproofed with a ¾-in. thickness of asphalt laid in two coats, and sealed along the side of the kerbs to the 2-in. mastic asphalt wearing surface of the carriageway (*Fig.* 15).

The parapet walls, piers, wing wall copings, and string-courses were all reinforced with ⅜-in. temperature bars (*Fig.* 16). The surfaces of the bridge parapet panels were bush-hammered. The surface of the wing wall panels was formed with self-bedded wallstones from 6 in. to 4 in. in thickness of a very fine-grained greenish-grey sandstone (*Fig.* 14).

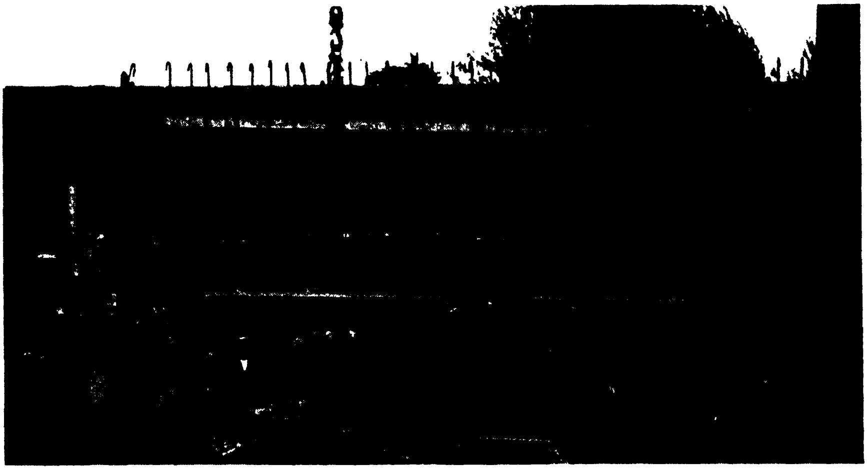


FIG. 17.—LONG PRESTON BRIDGE: FIRST PORTION COMPLETED.

The deck is designed to carry the standard loading of the Ministry of Transport, and consists of a 9-in. slab supported by ribs at 8-ft. centres, the ribs being 14 in. wide and 26 in. deep below the underside of the slab. The slab is designed for continuity except for the two end panels, the reinforcement consisting of ¾-in. main bars at 5½-in. centres, with ⅜-in. transverse bars at 7-in. centres, alternate main bars being cranked up over the ribs to take the reverse bending (*Fig.* 15).

The main intermediate beams are designed as T-beams and contain twelve 1⅜-in. bars with $\frac{7}{16}$-in. hoops, suitably placed to take the shear. The outer deck beams are designed as L-beams, similarly reinforced, and the parapet beams as simple beams with eight 1¼-in.

Quality " B " concrete used in all reinforced—and face—work consists of granite aggregate ¾-in. gauge to ⅛ in. in the ratio of 27 cub. ft. to 13½ cub. ft. of sand and 6 cwt. of cement. Quality " C " concrete in the abutments and wing walls contains, in lieu of granite, broken stone 2 in. to ⅛ in. and 5 cwt. of cement. Tests carried out during construction showed an average strength at 28 days for quality " B " concrete of 4,620 lb. per square inch, and for quality " C " 3,200 lb. per square inch, with slumps for quality " B " averaging 3 in.

The bridge was built in two portions,

the joint being made in the deck slab at a point of contraflexure by a "stepped" joint, and the reinforcement bent up temporarily as shown in *Fig.* 17.

The abutments and foundations presented no real difficulties, the maximum foundation toe load being 3 tons per square foot under the worst conditions. The river bed consisted of boulder gravel

FIG. 18.—SMITHIES BRIDGE: WEST ELEVATION OF OLD BRIDGE.

FIG. 19.—SMITHIES BRIDGE: WEST ELEVATION OF NEW BRIDGE.

to a depth of 5 ft., underneath which was boulder clay to which the foundations were taken. The water was dammed with puddle clay and carried clear of the excavations by a substantial chute. The bridge was constructed by the Yorkshire Hennebique Contracting Co., Ltd.

SMITHIES BRIDGE.

A new reinforced concrete barrel arch of 36-ft. span and 60 ft. between parapets has been constructed on the Leeds–Preston trunk road at Chatburn on the Lancashire–West Riding boundary to replace an old masonry arch (*Fig.* 18). The arch, 13 in. thick at the crown and 20 in. at the springing, has a rise of 6 ft. clear (5·88 ft. on a 37-ft. axis) and the axis was chosen to correspond with the line of thrust for dead load.

The design stresses adopted were 16,000 lb. per square inch in the steel and 800 lb. per square inch in the concrete, and the reinforcement consisted of ⅝-in. bars at 10-in. centres at the crown and ⅝-in. bars at 5-in. centres at the springing section. Shrinkage keys were left at the crown and near the springings, the former being closed about ten days after the remainder of the concreting had been completed.

The unusual arrangement of "skew-back" was necessary because of the low rise and the difficulties of withdrawing the cofferdam if the arch reinforcement

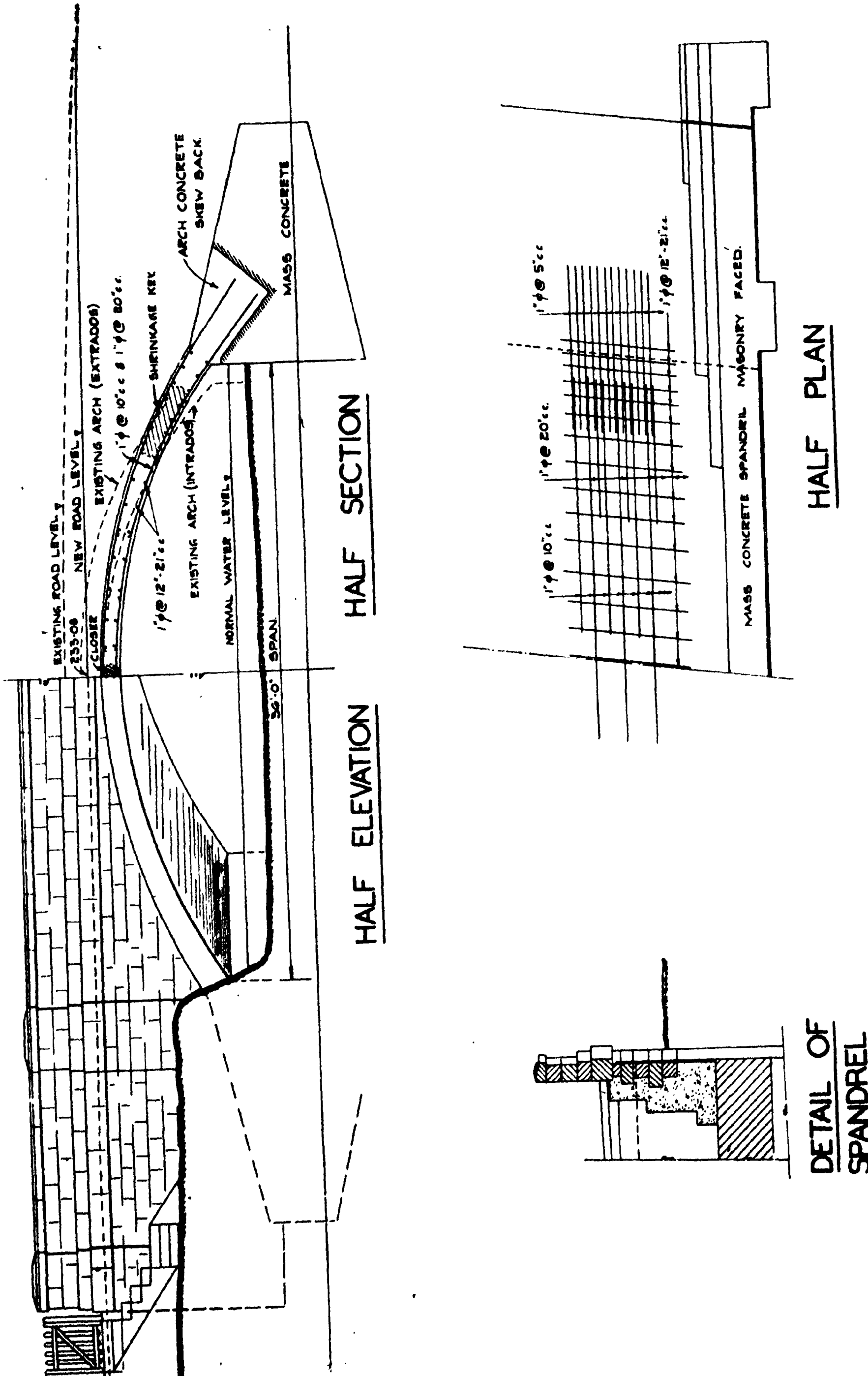


FIG. 20.—SMITHIES BRIDGE.

FIG. 21.—SMITHIES BRIDGE: OLD MASONRY ARCH DEMOLISHED AND FIRST HALF OF NEW BRIDGE COMPLETED.

had been placed in the mass concrete work first, added to the fact that the normal water level is only a few inches below springing level (*Fig.* 20).

A width of approximately 20 ft. was first constructed and a temporary roadway supported laterally over this portion by the rough rubble wall seen in *Fig.* 21, which shows the first portion completed. The spandrel walls are of mass concrete with ashlar facework.

The cost of the bridge (*Fig.* 19) was £2,600 or approximately £1·17 per square foot of area spanned, and the contract was carried out by Messrs. Fred Whitaker & Co., Ltd.

LOTS ROAD BRIDGE, NEAR DALTON-IN-FURNESS

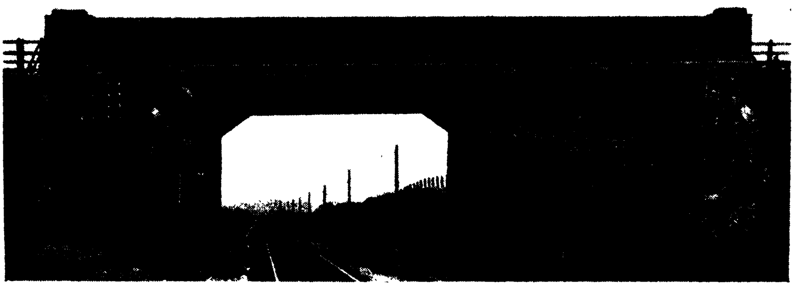


FIG. 22.

THIS bridge (*Fig.* 22) crosses the L.M.S. Railway near Barrow-in-Furness, replacing a brick structure which had become unsafe owing to decay of the brickwork. The original brick arch and abutment walls were removed, but the wing walls were incorporated in the new reinforced concrete structure. The new bridge is a rigid-frame structure, having frames spaced at 7-ft. 6-in. centres and is designed to carry Ministry of Transport loading. It has a clear span of 27 ft. 6 in., a width of 30 ft. (a 20-ft. roadway and two 5-ft. footpaths), and was constructed under the direction of Mr. E. B. Jackson, Surveyor to the Dalton-in-Furness Urban District Council. The British Reinforced Concrete Engineering Co., Ltd., acted as consulting engineers and supplied the designs and detail working drawings. The contractors were the Northern Ferro-Concrete Construction Co. (1935), Ltd.

BRIDGES IN HAMPSHIRE

Slab-and-Beam Construction.

In the County of Southampton three reinforced concrete road bridges have recently been completed and four more are under construction in accordance with the designs of the County Surveyor, Brig. A. C. Hughes, T.D., B.Sc., A.M.Inst.C.E. The bridges are interesting examples of slab-and-beam construction which has been to some extent standardised in the designs.

Bridges on the Totton By-Pass.

Partly because the line of the new Totton by-pass road passes between the schools and the residential area, and partly because there is heavy lorry traffic to and from the timber yards in Eling Lane which intersects the by-pass, it was decided to construct a fly-over bridge carrying the by-pass over Eling Lane which will enable the local and main road traffic to be separated. At the same time a pedestrian subway under the by-pass will be unnecessary.

The fly-over bridge is being built to carry dual carriageways and cycle tracks, but no footpaths will be provided since pedestrians following the line of the by-pass will naturally keep to the low level. Between the parapets there will be two 20-ft. roads separated by a 6-ft. strip and two 10-ft. 6-in. verges each accommodating a 6-ft. cycle track. The clear span over Eling Lane is 30 ft. 3 in. and the type of superstructure is simply-supported beam-and-slab construction with an 8½-in. slab on beams 2 ft. 6 in. deep by 1 ft. 10 in. wide and haunched at the ends for a distance of 4 ft. 6 in. so that the depth at the supports becomes 4 ft. 9 in. These beams are 5 ft. 9 in. apart and reinforced at midspan with four 1-in. bars in the top and twelve 1½-in. bars in the bottom.

The foundations are on gravel and the abutments, wing walls, and the retaining walls to the approaches (which are 300 ft. long) are constructed of mass concrete, the wing and retaining walls being faced with hand-made sand-faced bricks.

FIG. 23.—BRIDGE OVER SOUTHERN RAILWAY, TOTTON BY-PASS.

A second bridge (*Fig.* 23) is being constructed to carry the by-pass over the Southern Railway sidings at Totton, and has a skew span of 46 ft. Between the 13½-in. brick parapets the bridge will be 60 ft. wide with provision for an ultimate width of 80 ft. In the beam-and-slab floor the beams will be 5 ft. 2 in. apart, 3 ft. 9 in. deep overall, and 1 ft. 10 in. wide. At the ends there will be haunches 3 ft. 6 in. deep by 6 ft. long. The slab will be 8½ in. thick with ⅝-in. transverse bars at 4½-in.

centres both top and bottom, and ½-in. longitudinal distribution bars at 6½-in. centres in the bottom. In the main beams the reinforcement at midspan consists of four 1½-in. bars in the top, and six 1½-in. and six 1⅝-in. bars in the bottom. All the reinforced concrete is in the proportions of 1 : 2 : 4 and is being proportioned by weighing in a batching plant.

The contractors for these bridges are Messrs. John Howard & Co., Ltd., of Poole.

Bridges on the Ringwood By-Pass Road.

No. 1 bridge (*Fig.* 24) on this by-pass crosses the river Avon on the skew in two simply-supported 53-ft. spans (45 ft. 9 in. on the square) and at present carries a 7-ft. path, a 20-ft. carriageway, and a 10-ft. 6-in. verge. The superstructure comprises a slab-and-beam deck in which the slab is 8 in. thick and the beams are 4 ft. 8 in. apart. There are five main beams, each 1 ft. 10 in. wide by 4 ft. 6 in. deep overall, one permanent parapet beam, and one temporary parapet beam which is provided to allow the bridge to be widened in the future to carry dual carriageways each 20 ft. wide with a central verge of 6-ft. and two footways each 7-ft. wide.

The superstructure is carried on mass concrete abutments and piers supported on pre-cast reinforced concrete piles, and there are rocker bearings, equivalent to 11-in. diameter rollers, between the main beams and the abutments. There is an expansion joint protected by steel angles between the deck and the abutments, in which a clearance of ½ in. is provided between the angles. The concrete on the elevations of the bridge has been bush-hammered. The parapets are of brick-work with reconstructed stone copings.

No. 2 bridge on this road is also a beam-and-slab type over the river Avon, but there is only one span, in this case 38 ft. 6 in. Between the parapets the width is 37 ft. 6 in. Generally the design of the bridge is on similar lines to that just described. The deck slab is 8 in. thick, but the beams are 5 ft. 1 in. apart and their net section is 2 ft. 8 in. deep by 1 ft. 5 in. wide. In the slab the main transverse reinforcement is ¾-in. bars at 6½-in. centres both top and bottom, with ½-in. longitudinal distribution bars at 6½-in. centres in the bottom. In the beams there are five 1½-in. bars in the top and ten 1½-in. bars in the bottom at the middle of the span.

Both bridges were constructed in 1 : 2 : 4 concrete using ordinary Portland cement and local aggregates. The contractor was Mr. A. E. Farr.

FIG. 24.—BRIDGE OVER RIVER AVON, RINGWOOD BY-PASS.

Bridges on the Winchester By-pass Road.

Two beam-and-slab bridges are now under construction at Kingsworthy on the new Winchester by-pass road. The general lines of the designs are similar to those of the bridges on the Ringwood by-pass.

No. 1 bridge has two 44-ft. 9-in. skew spans, and between its parapets there is allowance for two 7-ft. 6-in. paths and two 20-ft. carriageways separated by a 10-ft. central verge. The piers, abutments and wing walls are being built in mass concrete. Owing to the considerable angle of skew the abutment faces are 102 ft. 9 in. long. Pre-cast concrete piles 40 ft. long and 14 in. square carry the abutments and piers. Masonite Tempered Presdwood is being used to line the shuttering on the exposed surface of the wing walls so as to obtain a fair face free from board marks. The beams are 5 ft. 9 in. apart with a web 1 ft. 9 in. wide and a total depth of 3 ft. 10½ in., including the 8½-in. deck slab.

No. 2 bridge is a simple skew span of 44 ft. (38 ft. 6 in. on the square) and otherwise similar in design to No. 1. The beams are 5 ft. 10 in. apart and their webs 1 ft. 8 in. wide. Including the 8½-in. slab the overall depth of the beams is 3 ft. 9½ in. In this bridge, also, the foundations are piled.

The contractor for the two bridges is Mr. A. E. Farr, who is also constructing the roadworks of the new by-pass.

Bridge over the Southern Railway at Havant.

This bridge (*Fig.* 25) was constructed in 1938 in order to replace an existing level crossing extending over two running lines and two sidings. There are two spans of 26 ft. 6 in. each on the square which have simply-supported ends and are continuous over a reinforced concrete pier in the middle. Between the parapets the bridge is 45 ft. wide and accommodates a 20-ft. road, with allowance for widening this to 30 ft. in the future, and two 7-ft. 6-in. paths. The parapets are of 13½-in. brickwork and the wing walls are faced with brickwork.

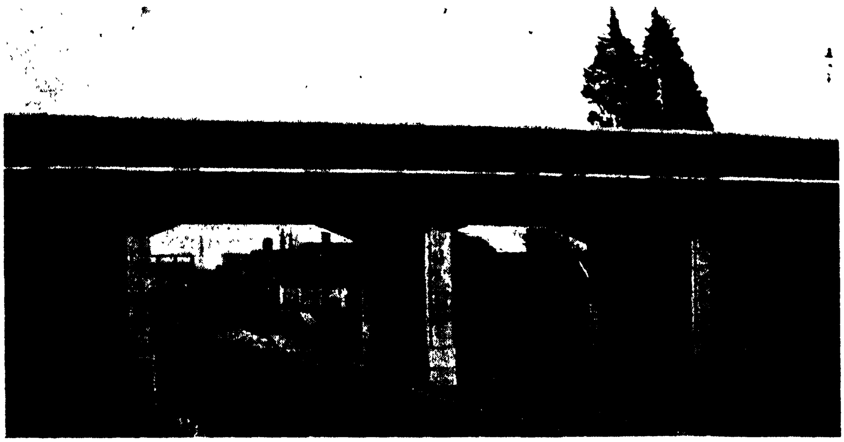


FIG. 25.—BRIDGE OVER SOUTHERN RAILWAY AT HAVANT.

The deck slab is 8 in. thick and is carried by beams 5 ft. 2½ in. apart, of which the net dimensions are 1 ft. 7 in. deep by 1 ft. 4½ in. wide. At midspan these beams are reinforced with eight 1⅛-in. bars in the bottom. The central pier has a minimum thickness of 2 ft. 10½ in. and is reinforced with ½-in. horizontal and vertical bars at 24-in. centres in both directions. Messrs. Caffin & Co., Ltd., were the contractors for this bridge.

MAISEMORE BRIDGE, GLOUCESTERSHIRE

Skew Span of 150 ft.

THE existing Maisemore bridge comprises two brick arches each of 50 ft. span and was erected under an Act of 1777. Originally a toll bridge, the tolls ceased when the cost of erection had been repaid. The repair of the bridge was vested in the bridge trustees, and certain common land was appropriated and the rents applied to the cost of repairs. The powers and assets of the bridge trustees have been transferred to the County Council under the Bridges Act of 1929.

FIG. 26.—MAISEMORE BRIDGE, GLOUCESTERSHIRE.

The existing road, Maisemore Causeway, runs parallel to and adjoins the bank of the river Severn (western channel) and approaches the bridge with a steep ramp and a sharp right-angle bend, and visibility is restricted to a few yards. In addition it has been found that the foundations of an old multi-span bridge remain in the bed of the stream, which, together with the existing bridge, considerably obstruct the flow of the river.

The new bridge (*Fig.* 26) provides a clear skew span of 150 ft. The proposed contract includes the removal of the old foundations, thus providing a greatly improved road alignment and an unobstructed channel for the river flow. The River Severn Catchment Board and the River Severn Commissioners are interested parties who have approved the scheme, and the former is contributing towards the cost. The County Surveyor, Mr. E. C. Boyce, B.Sc., A.M.Inst.C.E., is the engineer for the scheme on behalf of the Gloucestershire County Council, which is the responsible authority, and Messrs. Considère Constructions, Ltd., consulting engineers, and Major Stratton Davis, consulting architect, are collaborating in the preparation of the design and detail drawings of the bridge.

The new bridge will comprise two-hinged reinforced concrete ribs with an arched soffit slab, and the outer ribs are to be faced with local Cotswold stone (oolitic limestone). The elevation shows a thin concrete arch (the aggregate to be exposed and the materials to be selected to tone with the Cotswold stone) relieved by a narrow cut-stone arch with ashlar spandrels. Plain simple lines have been observed with the exception of rustication on the pier angles, and the perspective drawing (*Fig.* 26) shows the graceful lines of the elevation.

WHITEGATE ROAD BRIDGE.

Continuous Beam Construction.

THE bridge shown in *Fig.* 27 will carry Whitegate Road over the Northwich by-pass. It has been designed in the office of the County Surveyor, Mr. G. E. Ashforth, M.Sc., M.Inst.C.E., and is 120 ft. between abutments (120 ft. 3½ in. on skew). The width of the bridge is 45 ft. between parapets, and there will be a 20-ft. carriageway and two 6-ft. footpaths. The superstructure will be of continuous beam-and-slab construction, with three intermediate supports (columns), the central beams being 3 ft. 3 in. deep overall and spaced 8 ft. apart. The beams will be 12 in. wide and the slab 9 in. thick.

Both ends of the bridge will rest on cast-steel rocker bearings. The columns will be 3 ft. by 1 ft. 6 in. in section, with a cap beam 3 ft. 6 in. deep. They are designed as hinged at the top, and dowels are provided. The abutments are of the reinforced concrete counterfort wall type and entirely separate from the wing walls. The estimated cost of the bridge is £10,000.

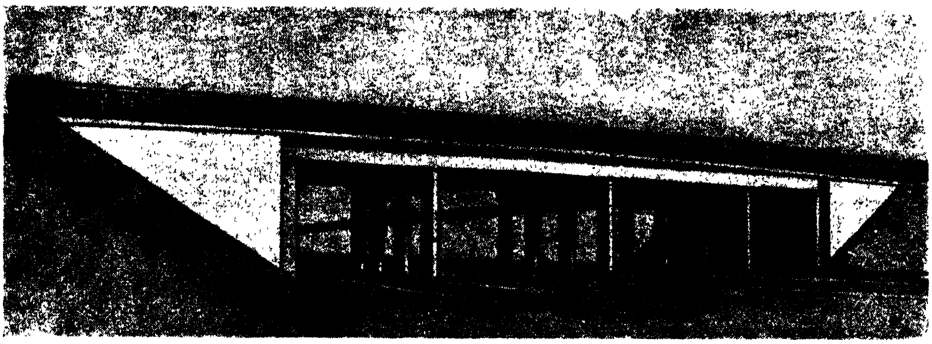


FIG. 27.—WHITEGATE ROAD BRIDGE, CHESHIRE.

GREENFIELD LOCK BRIDGE.

Width of 120 ft.

The Chester Ring Road, on which contract works were commenced in 1939 on a section two miles long immediately north and west of the City, will be carried over the Shropshire Union Canal by a reinforced concrete bridge 120 ft. wide between parapets and having a span of 49 ft. 4 in. on the skew. There will be 22-ft. dual carriageways, two 9-ft. cycle tracks and two 6-ft. footpaths. The type of bridge adopted is that with balanced cantilevers and a suspended span in the middle. The maximum headroom provided above weir level is 10 ft. 0⅜ in.

In the suspended portion the longitudinal beams will have spans of 26 ft. and will be 12 in. wide by 2 ft. 9 in. deep (min.) overall; they will be at 6-ft. centres and the deck slab will be 7½ in. thick. In the cantilever portions the balanced cantilevers will be 31 ft. long (overall) and will be supported on mass concrete piers 5 ft. thick.

The arms carrying the suspended span project 11 ft. 6 in. and consist of 9-in. ribs at 4-ft. centres with a 7-in. curved soffit slab, a 7-in. deck slab, and a trimmer beam. The balance arms are of cellular construction and will be loaded with selected filling; their projection is 14 ft. 6 in. and has an 8-in. base slab and 9-in. ribs at 4-ft. centres. The east elevation is illustrated in *Fig.* 28 and details of the design are shown in *Fig.* 30.

The bridge has been designed in the office of the County Surveyor. The total volume of concrete in the bridge is 1,660 cu. yd., and the weight of reinforcement 108 tons. The estimated cost is £11,000. Messrs. Tarmac, Ltd., are the contractors

Walton New Bridge.

This bridge (*Fig.* 29), now under construction, will carry a diversion of the Chester–Warrington road (A56) over the

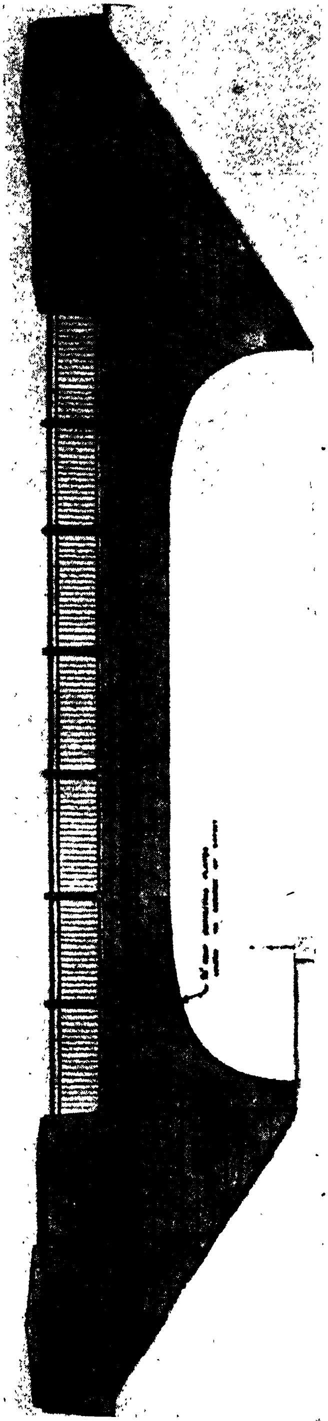


FIG. 28.—GREENFIELD LOCK BRIDGE, CHESHIRE: EAST ELEVATION.

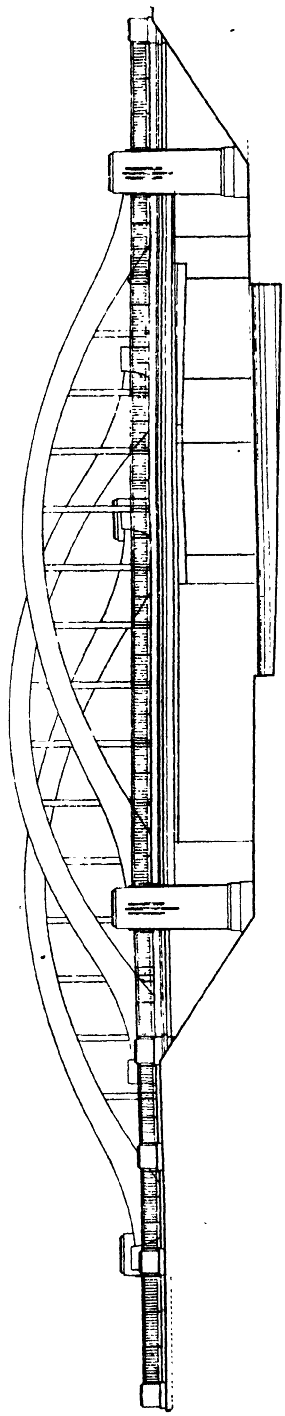


FIG. 29.—WALTON NEW BRIDGE, CHESHIRE.

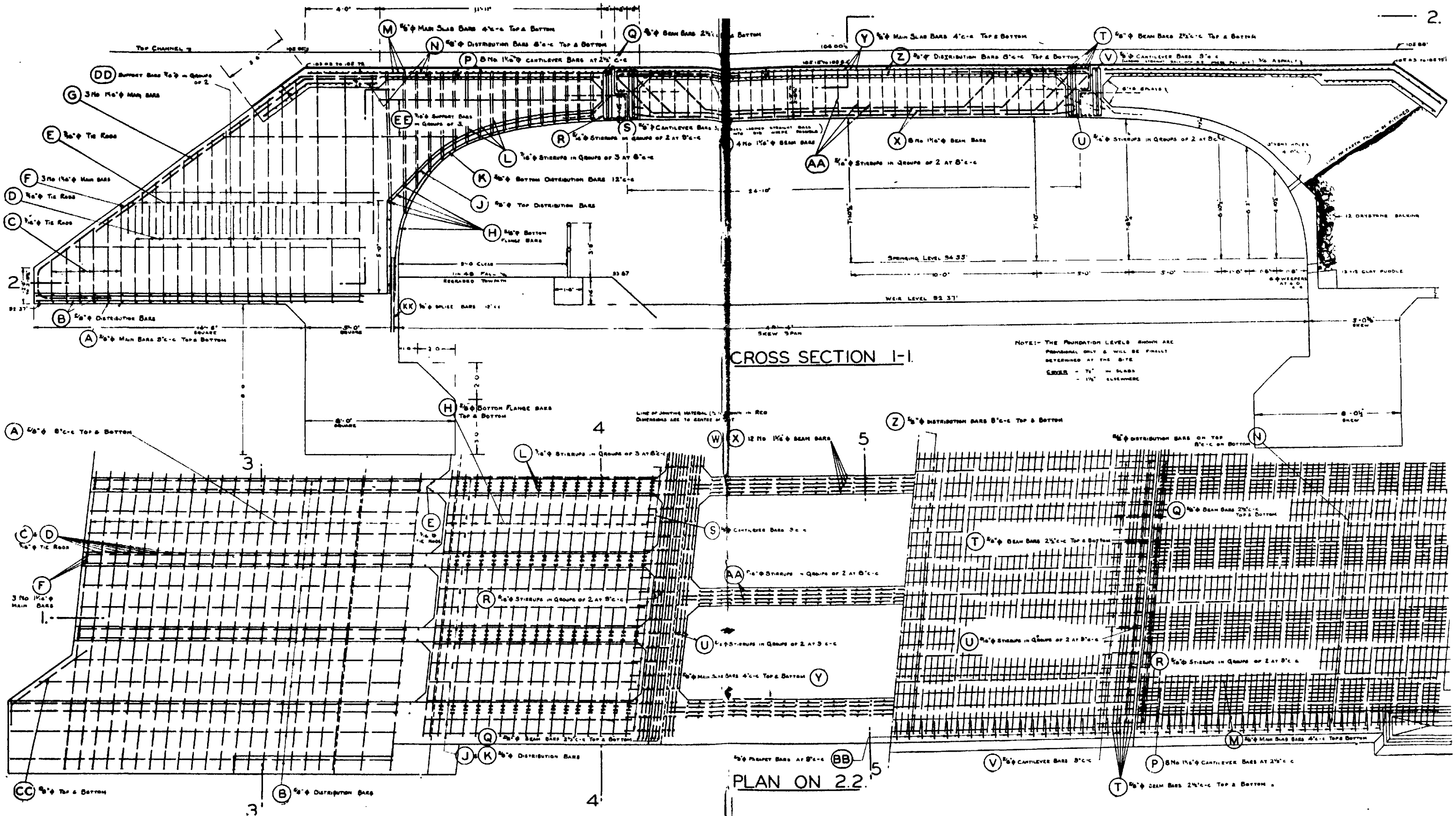


FIG. 30.—GREENFIELD LOCK BRIDGE, CHESHIRE.

Bridgewater Canal and replace an aqueduct carrying the canal over the present road, the roadway through the aqueduct being only 14 ft. 9 in. wide, with a headroom at the centre of 14 ft. The new road over the canal consists of 22-ft. dual carriageways with two 6-ft. footpaths, and the width of the approaches is 80 ft.; the clearance between water level and the underside of the new bridge is 13 ft. 7 in. at span centre. The gradients of the approaches are 1 in 30 on the south side and 1 in 21·5 on the north side, and the length of the road diversion is 800 yd. In the embankments there are about 63,500 cu. yd. of filling. The work is being executed in accordance with the plans of the County Surveyor, and Messrs. L. G. Mouchel and Partners, Ltd., are the consulting engineers for the bridge work.

The new bridge is a reinforced concrete bowstring with three tied arches having a clear span of 66 ft. on the square and 95 ft. 6 in. on the skew. Its overall width is 73 ft., and the two 8-ft. footpaths are cantilevered outside the two side arch ribs. The central arch rib is 111 ft. 3 in. long and its overall height is 28 ft. 10 in. The rib is 3 ft. by 3 ft. 6 in. in section at midspan and the section of the tie is 3 ft. by 4 ft. Both outer arch ribs are 116 ft. long by 26 ft. 3 in. high at the middle. The ribs measure 2 ft. by 3 ft. 6 in. at midspan, and the ties are 2 ft. by 4 ft. in cross section. Each arch is carried on rocker bearings on mass concrete piers, and between the piers there are reinforced concrete retaining walls 17 ft. high. These walls are counterforted and, like the piers, are carried on pre-cast reinforced concrete piles driven to rock and having an average length of 22 ft. 6 in. The overall length of each abutment is 81 ft. The total amount of concrete in the bridge is 1,710 cu. yd., and there are 231 tons of reinforcement. It is estimated that the bridge structure will cost £19,500. The Holborn Construction Co., Ltd., are the contractors.

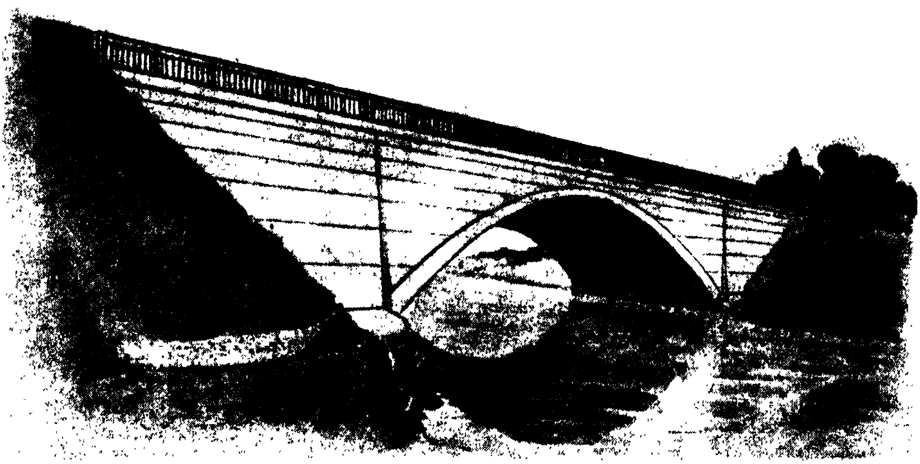


FIG. 31.—BRIDGE OVER THE RIVER DANE, CHESHIRE.

Bridge over the River Dane.

Where the Congleton by-pass road crosses the river Dane it will be carried on a reinforced concrete arch bridge having a skew span of 60 ft. and a square span of 51 ft. 11 in. The width between the parapets will be 60 ft., accommodating a 30-ft. carriageway, two 6-ft. footpaths and two 9-ft. grass verges. The road is on a gradient of 1 in 20 at the site of the bridge.

The design provides for an arched vault having a rise of 15 ft. 6 in. and thicknesses of 1 ft. 3 in. and 1 ft. 6 in. respectively at the crown and springings. The abutments will be mass concrete 13 ft. 9 in. wide on the square, 10 ft. deep at the front and 5 ft. deep at the back. They will rest on rock. Reinforced concrete will be used for the spandrel walls and wing walls, which will have cantilevered ends. The parapets will be wrought iron. The estimated cost of the bridge (*Fig.* 31), which has been designed in the office of the County Surveyor, is £9,500.

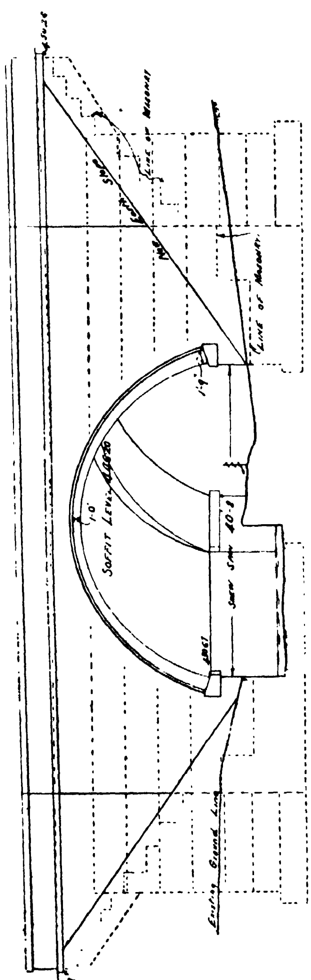


FIG. 32.—ELEVATION.

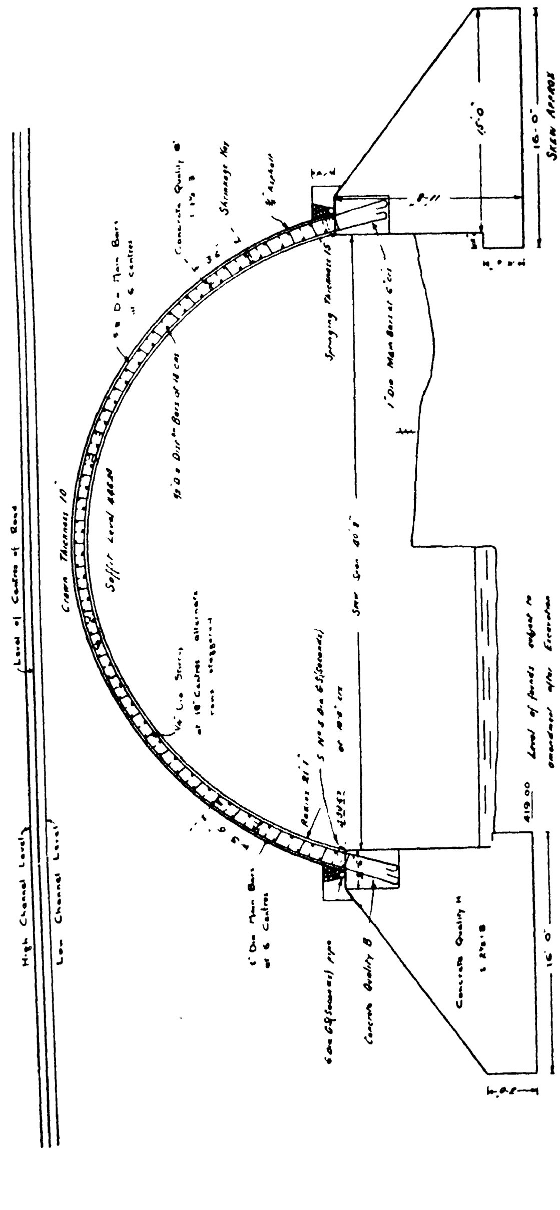


FIG. 33.—SECTION.

MILLBROOK BRIDGE, CHESHIRE.

Millbrook Bridge.

The existing Millbrook bridge on the Mottram-Woodhead road (A628) is a stone arch with a span of 40 ft. and a width of 24 ft. between parapets. This is to be strengthened and widened to 65 ft. in accordance with a design prepared in the County Surveyor's office.

Over the stone arch a saddle of reinforced concrete will be 9 in. thick at the crown and 12 in. at the skew-backs. It will be reinforced with ½-in. longitudinal bars at 6-in. centres in the extrados and intrados, with ½-in. transverse bars at 1-ft. 6-in. centres top and bottom; these will be tied together by ¼-in. stirrups at 1-ft. 6-in. centres with alternate rows staggered. At 12 ft. on either side of the crown there will be a splice in the longitudinal reinforcement. A ⅜-in. Ruberoid joint will be made between the existing bridge and the new structure so as to allow for possible settlement of the latter.

The new part of the bridge (*Fig.* 32) will be a reinforced concrete arch slab with a skew span of 41 ft. and a rise of 15 ft. 6 in. The thickness will be 10 in. at the crown and 15 in. at the springings. Details of the reinforcement and abutments are shown in *Fig.* 33. Stone-faced reinforced concrete will be used in building the wing walls and the ends of these will be cantilevered. The cost, exclusive of road works, is about £5,000. Messrs. William Storrs, Sons & Co., Ltd., are the contractors.

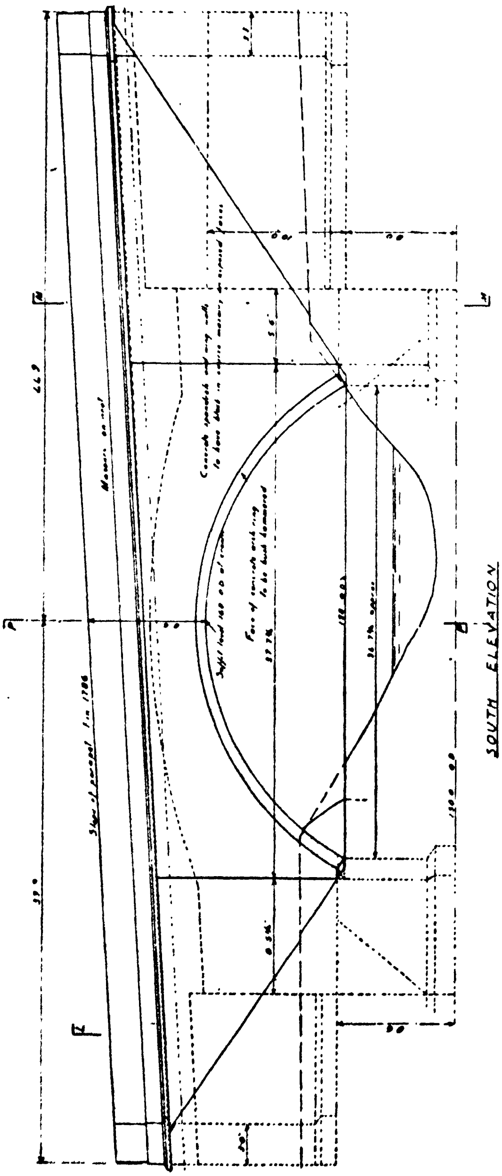


FIG. 34.—OLDMILL BRIDGE, CHESHIRE.

Oldmill Bridge, Dodcott.

Construction of half the width of the bridge at a time is being adopted in replacing the existing stone arch bridge at Dodcott by a reinforced concrete arch bridge (*Fig.* 34) of the same span but 50 ft. between the parapets. The bridge, which has been designed in the County Surveyor's office, carries the Whitchurch–Audlem road (A525) over the river Weaver and has a square span of 30 ft. and a span of 34 ft. 8 in. on the skew. The rise is 10 ft. and the thickness of the arch is 9 in. at the crown and 12 in. at the springing. The abutments and wing walls are mass concrete, and the spandrels and wing walls will be faced with masonry. The parapets will also be constructed in masonry.

Shrinkage keys 2 ft. 6 in. long are provided in the arch slab at 15 ft. on either side of the crown and the main reinforcement is lapped at these points. In the central portion of the arch these bars are ⅝-in. diameter at 6-in. centres, and from the keys to the abutments are ¾-in. diameter. The intrados is a circular arc of 20 ft. radius.

The abutments are 8 ft. wide and are founded on shale. Their depth is 8 ft. 6 in. Exclusive of roadworks, the estimated cost is £4,000. The contractors are Messrs. Bethell & Sons, Ltd.

HALL DUNNERDALE BRIDGE, CUMBERLAND

Anchorage of Main Bars in Rock.

THIS is a joint bridge maintained by the Cumberland and Lancashire County Councils over the river Duddon. It is situated on the unclassified county road from Ulpha to Seathwaite on the fringe of the Lake District. Before reconstruction the bridge was a hump-backed masonry structure with bad angles of approach which obscured visibility. The average width between the parapets was 11 ft. A section through the arch and abutments of the new bridge is shown in *Fig.* 35.

The new bridge is a reinforced concrete arch, 40 ft. span, designed for the Ministry of Transport Standard Loading, and is faced with a greyish green local stone in order to keep its appearance in harmony with the surrounding district. The parapet walls are also built of local stone. The width between the parapets is 25 ft. and provides for a 20-ft. carriageway with a 4-ft. footpath on the downstream side and a 1-ft. traffic guard on the upstream side. The gradients and angles of approach were considerably improved by carrying out the scheme. A cross section at the crown is shown in *Fig.* 37 (given on page 35).

The arch springs from abutments of solid rock which were carefully trimmed and stepped to receive the concrete. Its thickness is 12 in. at the crown and 24 in. at the springings and it is reinforced as in the details in *Fig.* 36 (page 34). An interesting feature of the details is the method of anchoring the main bars in the rock at the abutments. Improved drainage facilities have also been provided to deal with flood water.

The estimated cost of the work was £2,915, towards which the Ministry of Transport made a 50-per cent. grant; the balance was equally defrayed by the counties of Cumberland and Lancashire. The scheme was designed by the technical staff under the supervision of Mr. G. O. Lockwood, M.Inst.C.E., F.S.I., County Surveyor and Bridgemaster of Cumberland, and the work was carried out by direct labour.

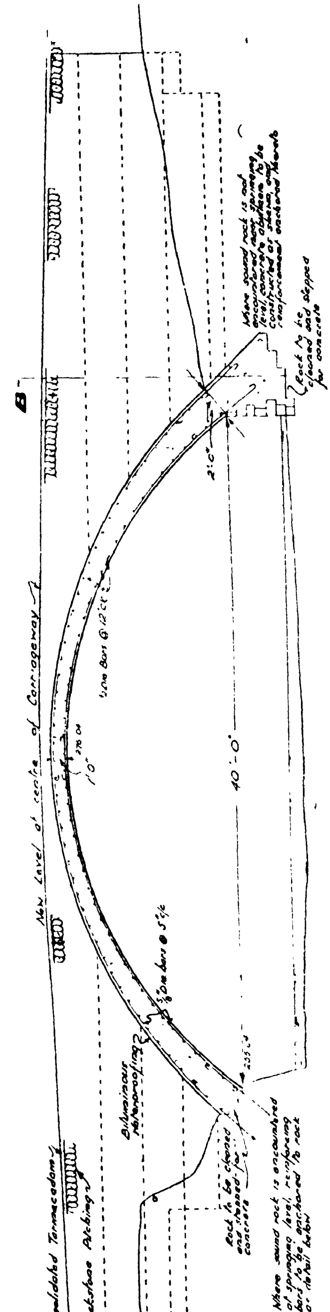


FIG. 35.—HALL DUNNERDALE BRIDGE: SECTION THROUGH ARCH AND ABUTMENTS

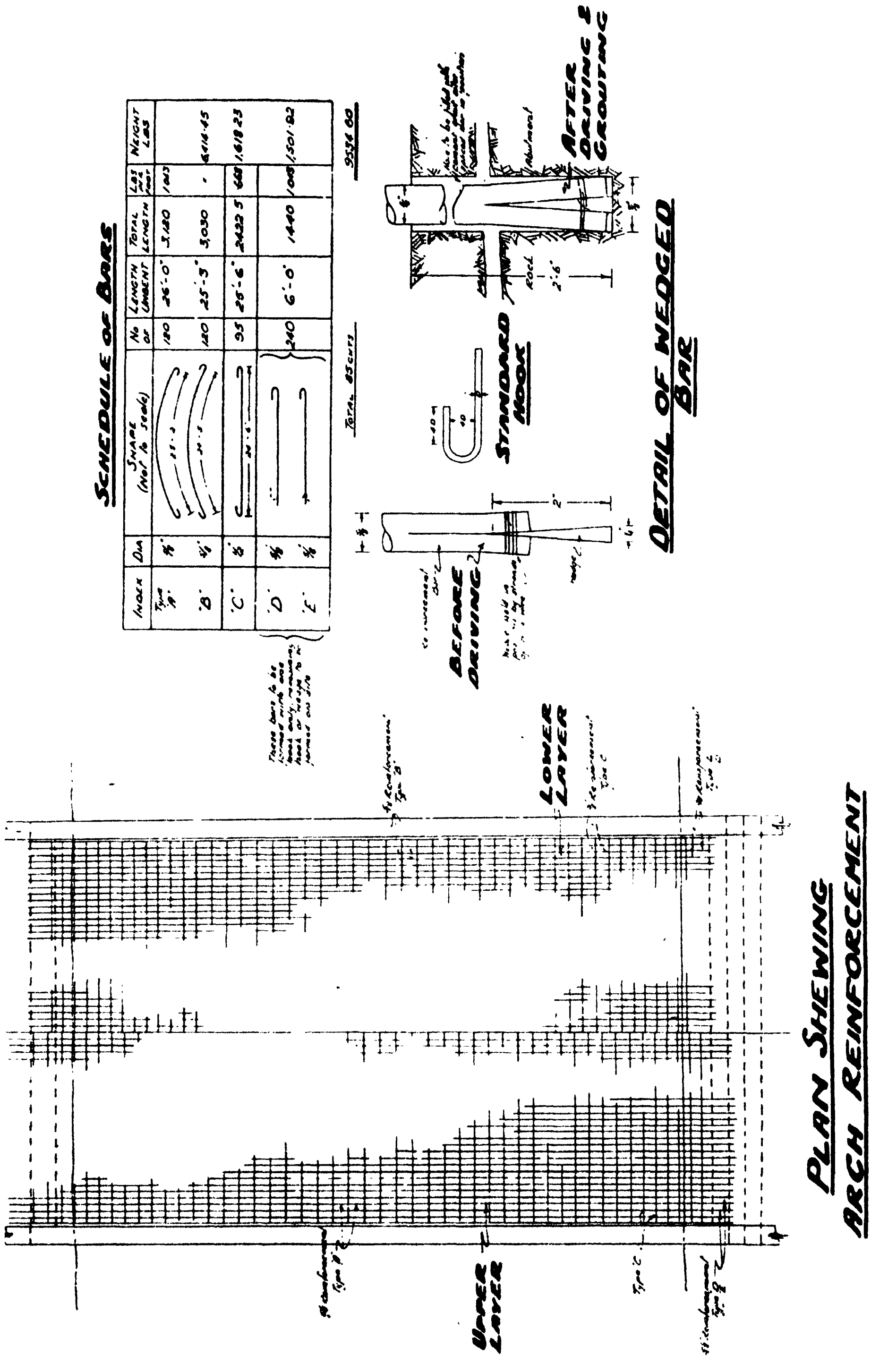


FIG. 36.—HALL DUNNERDALE BRIDGE, CUMBERLAND. (*See page* 33.)

Portal Frame of 50 ft. Span.

THIS structure, now nearing completion, has been designed by Mr. P. Schofield, County Surveyor and Bridgemaster of Lancashire, to carry the new Formby by-pass road over the river Alt. It is a composite structure, consisting of a reinforced concrete portal sandwiched between plate girders supporting pipe bays. In this case the steelwork was undisguised, so that in elevation the appearance is that of a steel girder bridge. The square span is 50 ft. and the span on the skew 54 ft. $1\frac{7}{16}$ in. The width between the parapets is 120 ft.

Foundation and Design.

Owing to the poor nature of the ground the design of the foundations for the portal frame presented considerable difficulty, as little reliance could be placed on the material at the backs of the portal bases to resist the induced horizontal thrust. Trial calculations were made incorporating raking piles, but the rake required was deemed to be excessive and it was considered advisable to provide horizontal ties between the bases. The general design and dimensions of the frame are as follows: span 50 ft., rise 3 ft., thickness at crown 21 in., thickness at springing 4 ft. 9 in., height of leg above base 14 ft. 6 in., average thickness of leg 3 ft. 6 in. At the middle of the span there are $\frac{7}{8}$-in. longitudinal bars at 3-in. centres in the top of the rib and 1-in. and $\frac{7}{8}$-in. bars alternately at 3-in. centres in the bottom. At the ends of the ribs the top reinforcement is $\frac{3}{4}$-in. bars at 2-ft. 6-in. centres which are extended into the legs of the frame. The bottom of the rib at its ends and the inner legs of the frame are also reinforced with $\frac{3}{4}$-in. bars at 2-ft. 6-in. centres. The legs are hinged at the junction to the base. The base, 5 ft. wide by 3 ft. 6 in. thick, is carried on a double row of 14-in. by 14-in. pre-cast reinforced concrete piles at 5-ft. centres. The ties are 14 in. by 10 in. at 10-ft. centres, and reinforced by six $1\frac{3}{8}$-in. bars. The piles are required to bear a calculated load of 44 tons each, and the ties a force of 62 tons each.

The hinges were constructed by crossing the reinforcing bars at the junction of the leg and the base, a thin layer of bituminous filling being laid to allow of

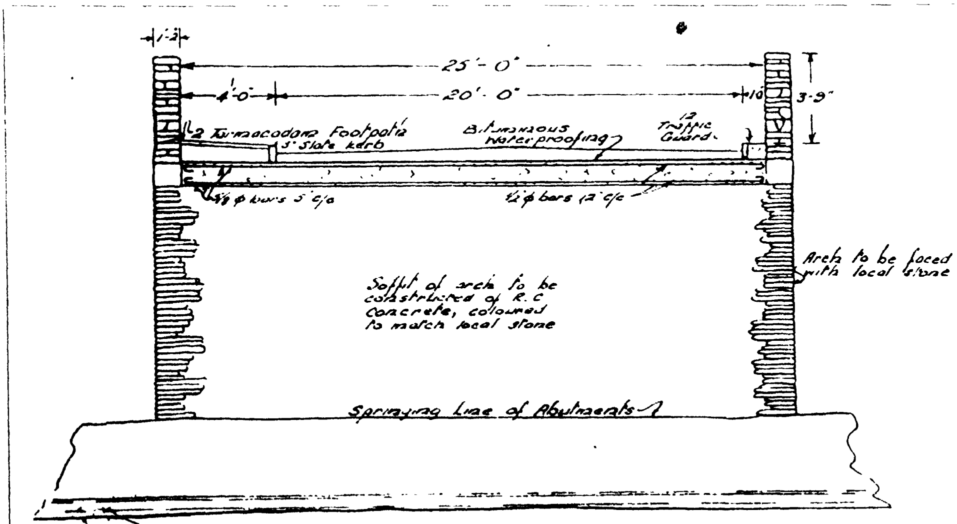


FIG. 37.—CROSS SECTION THROUGH CROWN OF ARCH.
HALL DUNNERDALE BRIDGE, CUMBERLAND. (*See page* 33.)

slight relative movement and in some measure to protect the steel. The hinge bars are further protected by continuous strips of copper set in the concrete on each side of the hinge. As the hinges are below river level, it was considered essential to preserve the hinge bars from corrosion. Various other methods had been examined, such as pickling and galvanizing the bars, using stainless steel, sheathing the bars with copper tubes, metal spraying, etc., but had been rejected as being either too costly or unsuitable.

Construction.

The main difficulty was placing the ties, as the volume of water to be dealt with precluded the adoption of end dams and a flume. A main central wooden pile dam was first driven, with pockets, in plan about 4 ft. by 4 ft., on the line of each tie. The portal base and ties on one side of the river were then placed. The ends of the ties in the centre of the river were left with the reinforcement projecting about 2 ft., the bars being screwed to take flanged couplings. At a later stage, with the centre dam still in position, the pockets were reversed to allow of a connection being made between the ties already fixed and the remaining halves on the other side of the river. Considerable difficulty was experienced in joining the ties by means of the couplings, and it was considered that a better method in future would be plain lapping of the bars.

Effects of Vibration.

The portal legs being completed, centering and shuttering to the decking were fixed for the complete 80-ft. width of the portal, and the concrete was placed in longitudinal bays on seven successive working days. Electric vibrators of the immersion type were used during the concreting of three of the deck bays, the remainder being hand tamped. When the shuttering was stripped the soffit was uniformly good and free from honeycombing. The bays which were hand tamped seemed, however, to be slightly "greener" in appearance. Test cubes were made of the two types of concrete during the progress of the work. The average crushing load of a hand-tamped 6-in. cube was 123,000 lb. at 17 days, as against 186,000 lb. for the vibrated cubes, the comparative weights being 18 lb. 11 oz. and 19 lb. 1 oz. respectively. The mix used was 4 : 2 : 1 by volume, using ¾-in. to ¼-in. graded granite aggregate, pit sand, and ordinary Portland cement. Messrs. Williams, Tarr & Co., Ltd., are the contractors.

HORNBY BRIDGE, LANCASHIRE

Widening from 16 ft. 9 in. to 45 ft.

This bridge, which is scheduled as an ancient monument, is situated below Hornby Castle on the banks of the river Wenning, and carries the Lancaster–Kirkby Lonsdale road (A683) over the river.

The present bridge, an imposing structure in ashlar masonry, consists of three arches (a centre span of 56 ft. 6 in. and two side spans of 44 ft. 6 in.), but as it is only 16 ft. 9 in. wide between parapets it is entirely unsuited to the large amount of traffic to and from Yorkshire during the summer months. Furthermore, the existing approach gradients of approximately 1 in 15 give unsatisfactory visibility over the bridge.

The present scheme has been prepared by Mr. P. Schofield, County Surveyor of Lancashire. It entails widening the existing structure on the west side to a width between parapets of 45 ft. which, with a further widening on the east side of 15 ft. in the future, will give an ultimate width of 60 ft. The arches will be widened in reinforced concrete and the whole of the facework as existing will be repeated in ashlar in the new elevation. The approach gradients are being improved to 1 in 20. The bridge widening forms part of a general improvement scheme through the village of Hornby and has already received the approval of the Ministry of Transport.

FIG. 38.

PONTARDULAIS bridge, over the river Loughor, is a reinforced concrete open-spandrel arch with a clear span of 79 ft. 3 in. on the skew. The angle between the centre line of the bridge and the river is 71 deg. 34 min., and the width between the parapets is 40 ft. which accommodates a 30-ft. carriageway and two 5-ft. paths. There are four arched ribs spaced at 12-ft. centres and having a rise of 12 ft. 6 in.; the inner ribs are 5 ft. wide and the outer ribs 3 ft. 6 in. wide. The abutments were constructed of mass concrete, and were founded on gravel 14 ft. below the bed of the river.

The bridge (*Figs.* 38 to 40) was designed by Mr. E. Charles Pole, County Surveyor of Glamorgan, and the contractors for the work were Messrs. John Morgan (Builders), Ltd., of Cardiff.

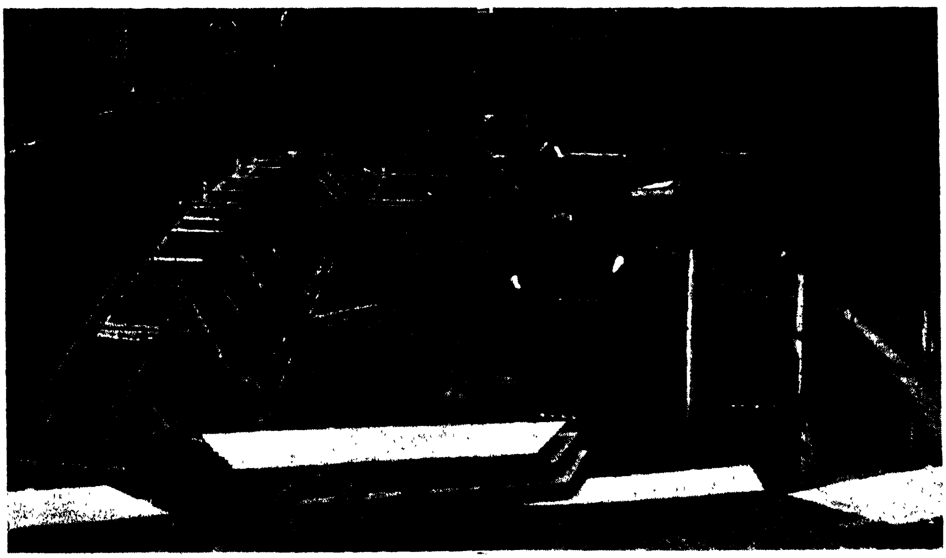
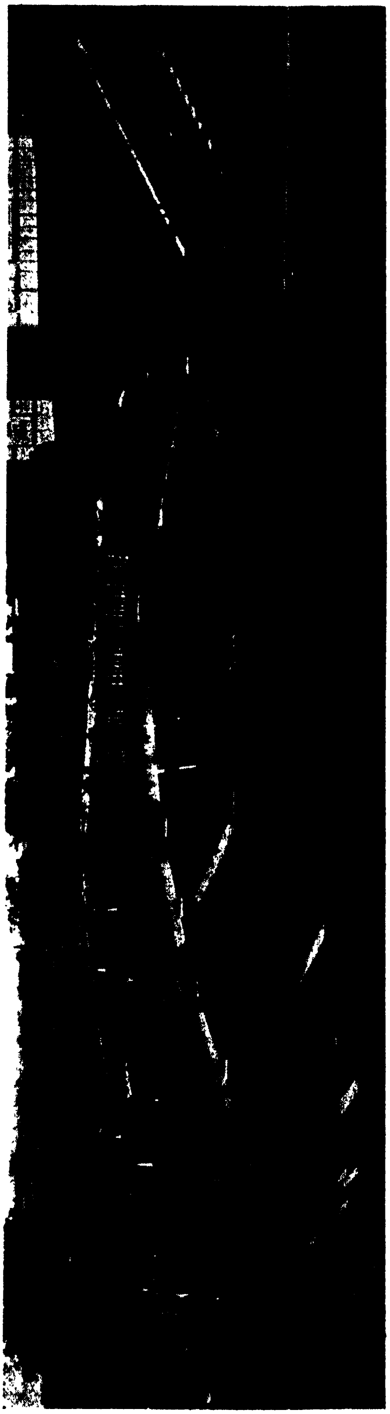
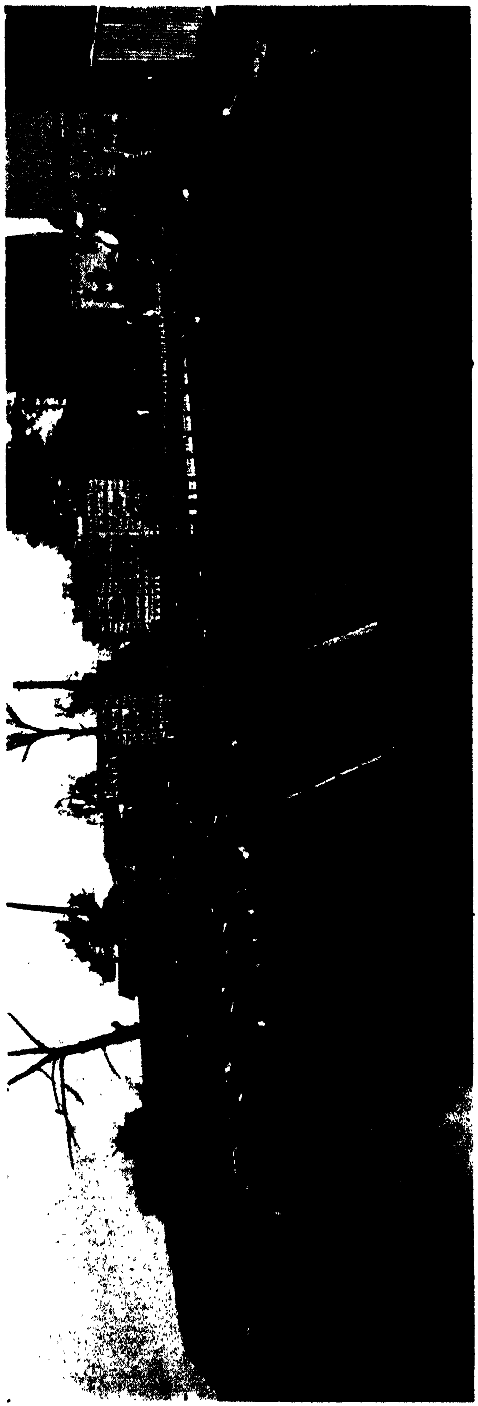


FIG. 39.—ARCH UNDER CONSTRUCTION.



REINFORCEMENT ASSEMBLED.



ROAD UNDER CONSTRUCTION.

FIG. 40.—PONTARDULAIS BRIDGE, GLAMORGAN.

LEWISBURN BRIDGE, NORTHUMBERLAND

Precautions against Floods during Construction.

THE existing bridge, built in 1829 over the Lewis Burn near Kielder on the Bellingham–Kielder road, in addition to being narrow and hump-backed and situated on a dangerous bend, showed signs of inability to carry the increased weight of traffic, and was scheduled as a weak bridge by the Northumberland County Council. A new bridge was decided upon and at the same time advantage was taken of the opportunity to improve the alignment of the road, at an estimated cost of £3,900 for the bridgeworks and £3,700 for the road works. A grant having been made towards the cost by the Ministry of Transport and the approval of the elevation by the Royal Fine Art Commission being given, the work was carried out in accordance with plans prepared by Mr. Alex. Cheyne, A.M.Inst.C.E., F.S.I., the County Surveyor of Northumberland.

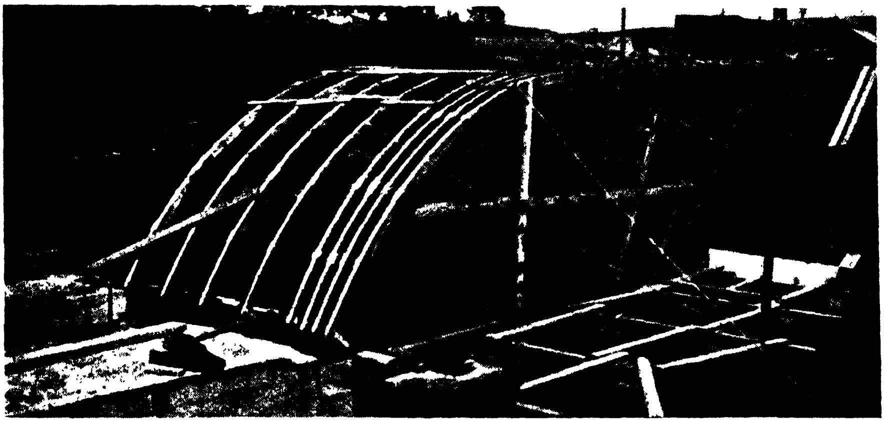


FIG. 41.—CENTERING FOR ARCH SLAB.

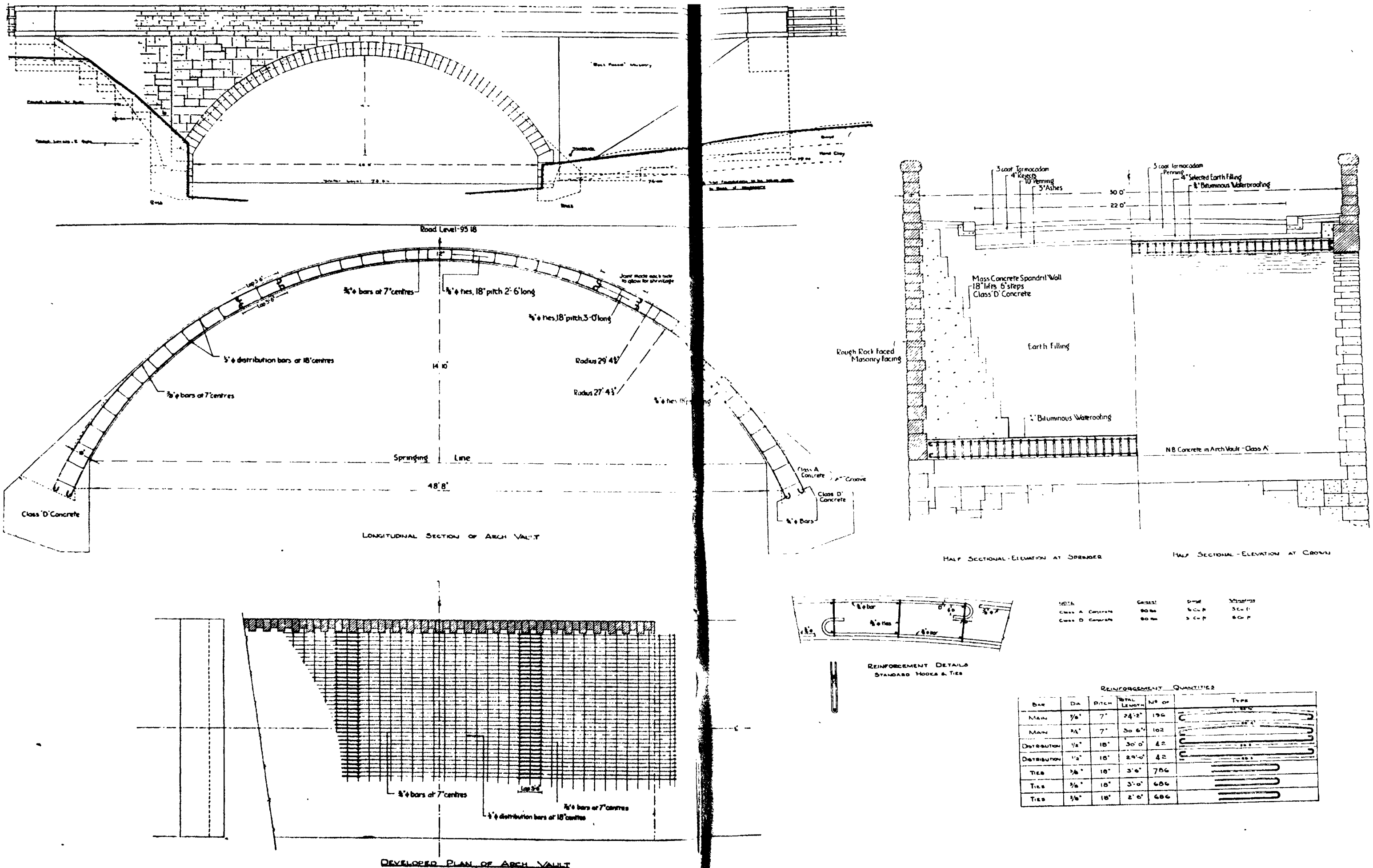
Design.

The new bridge is a reinforced concrete segmental arch with masonry facings, and has a clear span of 48 ft. 8 in. and a rise of 14 ft. 10 in. The width between the parapets is 30 ft. At the crown the arch is 12 in. thick and reinforced with $\frac{3}{4}$-in. bars at 7-in. centres; at the springings it is 18 in. thick and reinforced with $\frac{7}{8}$-in. bars at 7-in. centres. The distribution bars are $\frac{1}{2}$-in. at 18-in. centres and the ties $\frac{3}{8}$-in. bars at 18-in. centres. In the reinforced work the concrete was composed of 1 part of rapid-hardening Portland cement to $1\frac{1}{2}$ parts of sand and 3 parts of whinstone aggregate graded from $\frac{1}{8}$ in. to $\frac{3}{4}$ in. Compression tests of 6-in. cubes at 7 days showed an ultimate strength of 5,000 lb. per square inch. In the abutments and wing walls the mass concrete is 1 : 3 : 6 mix, ordinary Portland cement being used and the whinstone graded up to $2\frac{1}{2}$ in. gauge. Drawings of the bridge are given in *Fig.* 42 on pages 40 and 41.

Construction.

The abutments are founded on a very hard compact sandstone of a quartzitic character, dipping in a northerly direction. The dip was favourable to the construction of the south abutment, but on the north side particular attention was given to stepping and roughening the rock foundation in order to increase the resistance to sliding on the sloping surface.

As drilling the rock proved laborious and expensive, blasting was resorted to, but only very light charges were allowed so that shattering of the foundation would not occur. The south approach retaining walls are founded on rock. The north



Bar	Dia	Pitch	Total Length	No. of	Type
Main	⅞"	7"	24'-2"	196	
Main	¾"	7"	30' 6"	102	
Distribution	½"	18"	30' 0"	42	
Distribution	½"	18"	29'-0"	42	
Ties	⅜"	18"	3' 6"	786	
Ties	⅜"	18"	3'-0"	686	
Ties	⅜"	18"	2' 6"	686	

FIG. 42.—LEWISBURN BRIDGE.

walls are founded on seggar clay; here a vee-joint has been made between the spandrel walls and the approach retaining walls, a bituminous felt layer being introduced between the faces of the joint to allow for possible unequal settlement due to different types of foundation.

The centering consists of nine timber by 10-in. sills, which are in turn bolted down to five 15-in. by 18-in. concrete pillars (*Fig.* 43) cast in situ on the rock bed of the river. The pillars are dowelled 6 in. into the rock with ¾-in. diameter steel bars. Extra care has been taken to secure the centering and supports against floods. The burn rises very rapidly and

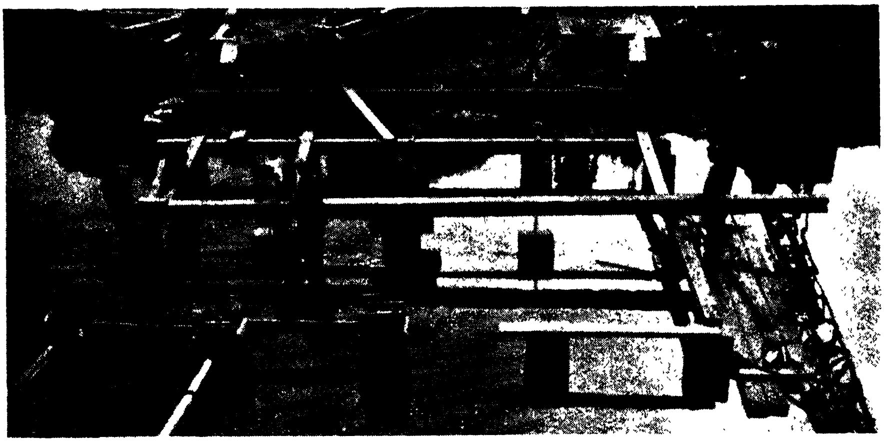


FIG. 43.—CONCRETE PILLARS TO SUPPORT CENTERING.

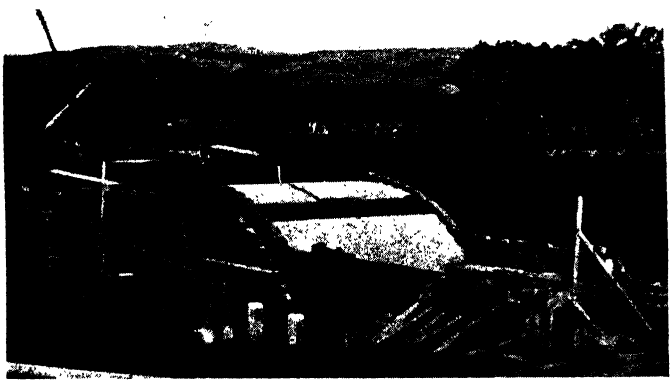


FIG. 44.—BRIDGE UNDER CONSTRUCTION.

arch trusses (*Fig.* 41) at approximately 4-ft. centres braced transversely and longitudinally. The curved rib is cut out of 9-in. by 4-in. timber, the tie beam is 12-in. by 4-in. pitch pine, and the struts and braces are each composed of two 9-in. by 3-in. timbers notched one on each side of the rib and tie beam.

The trusses are wedged up off five 10-in. is soon a raging torrent after a heavy downfall of rain. As a precaution, a wire rope has been stretched across the river about 50 yards upstream to intercept floating debris and trees. In addition, the centres have been guyed with wire ropes, anchored to the banks, one on each side.

The shuttering to the arch vault consists of 6-in. by 2-in. dressed redwood,

grooved on each side and fitted with oak tongues.

The walls up to road level are faced with rock-faced sneck rubble sandstone; above the stringcourse the parapet consists of rock-faced block-in-course sandstone. A general view of the bridge and wing walls under construction is shown in *Fig.* 44.

The whole of the work contract was carried out by direct labour, and the bridgework was completed at the end of the year 1938.

NEWBRIDGE, WOLVERHAMPTON

Comparative Cost of Two Designs.

THE reconstruction of this bridge in accordance with plans prepared by Mr. H. B. Robinson, M. Inst. M. & Cy. E., Borough Engineer of Wolverhampton, has recently begun and is expected to be completed in nine months.

The new bridge (*Fig.* 45) will be 67 ft. 6 in. in width and will have a central clear span of 46 ft. 6 in. and side spans of 23 ft. and 19 ft. It will carry two 20-ft. carriageways separated by a 4-ft. strip and there will be two footpaths 10 ft. in width with pipe ducts below them. Each span will be simply supported. The large span will be of beam-and-slab construction composed of two parapet beams, two kerb beams, and six road beams spaced at 6-ft. 6-in. centres. These beams will be 1 ft. 9 in. wide by 3 ft. 10 in. deep exclusive of the 8-in. reinforced concrete slab. In the end spans the construction is a slab without beams; this is 18 in. thick in the 23-ft. span.

The piers are designed as concrete walls with lightening openings 9 ft. high by 3 ft. 6 in. wide spaced so that there is a column below each girder in the central span. Below the pipe ducts these openings will be 7 ft. wide by 7 ft. 6 in. high. The piers will be founded on bored concrete piles.

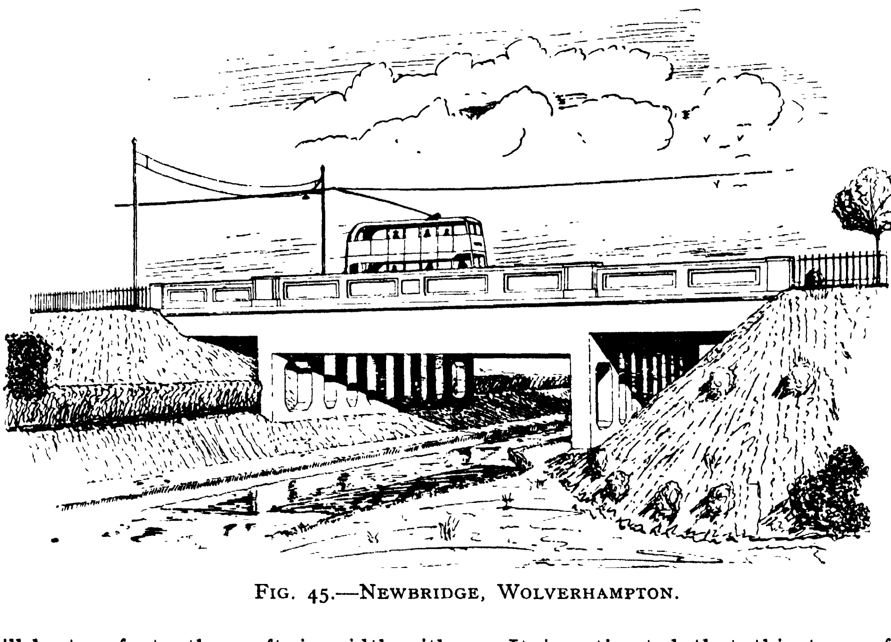


FIG. 45.—NEWBRIDGE, WOLVERHAMPTON.

It is estimated that this type of construction with earth embankments will effect a saving of about 25 per cent. compared with an alternative scheme with a clear span of 27 ft. and mass concrete abutments and wing walls.

Messrs. Currall, Lewis & Martin, Ltd., of Birmingham, are the contractors for the reconstruction.

RECONSTRUCTION OF ISLA BRIDGE, ABERDEENSHIRE

Reinforced Concrete Bridge built on existing Masonry Piers.

THIS bridge on Route B9022 spanned the river Isla with three masonry arches of 25 ft., 35 ft., and 25 ft., and was very hump-backed. Though the approach roads were well aligned the steep gradients up to the bridge, combined with the bad visibility and narrow carriageway without footpaths, constituted a danger to traffic. As the road, though a comparatively important through route, is not a Class I road it was desired to effect an improvement with the least expenditure.

Investigation having proved that the existing abutments and piers were in sound condition, it was decided to remove the existing masonry arches and strip down the abutments and piers to springing level. Reinforced concrete cantilevered saddles were then built over the existing piers and abutments (*Fig.* 46), the bridge deck being formed of longitudinal girders with a road slab. The five main beams are spaced at 6-ft. centres and are 27 in. by 14 in. in section with 6-in. by 6-in. splays at their junction with the 8-in. deck slab. The old masonry parapets were dressed and rebuilt. The width between parapets, originally 12 ft., is now 26 ft., giving a 20-ft. carriageway with a 5-ft. footpath and 1-ft. safety verge. All concrete is 3 : 2 : 1 mix, and for all exposed concrete facework "Keytex" shutter lining was used. The resulting corrugations were rubbed down with concrete blocks and the effect is very pleasing. The reconstruction resulted in the road level at the middle of the bridge being reduced by 7 ft. 3 in.

FIG. 46.—NEW BRIDGE ON EXISTING PIERS.

The consulting engineers for this improvement, which was undertaken by Mr. M. Heddle, County Road Surveyor of Aberdeenshire, in conjunction with Banff County Council, were Messrs. F. A. Macdonald & Partners (Glasgow), Ltd., and the work, now practically completed, was carried out by Mr. D. C. Stewart, of Aberdeen. The total cost of the scheme is about £4,800.

LINDFIELD BRIDGE, EAST SUSSEX

Widening on Cast-in-Situ Piles.

LINDFIELD bridge on the Crawley Down–Haywards Heath road, which is a narrow structure with a steel trough deck carrying the road over the river Ouse, has recently been widened in reinforced concrete. The widening is a three-span slab bridge carried on cast-in-situ piles. It is 22 ft. 11 in. wide at one end and 30 ft. 7 in. wide at the other. The spans are 19 ft. 6 in., 24 ft. 6 in., and 19 ft. 6 in. between centres, and the two outer spans are cantilevered over the inner supports so that the middle span is a simply-supported slab 18 ft. long. Between the middle and end spans there are halved joints in the slabs. All slabs are 1 ft. 8 in. thick, and are carried on capping beams 3 ft. deep by 3 ft. wide over the two interior supports and 2 ft. 6 in. wide over the two end supports. The supports consist of 17-in. minimum diameter piles formed in situ under pressure; the piles are 25 ft. long under the ends and

FIG. 47.—LINDFIELD BRIDGE.

FIG. 48.—LINDFIELD BRIDGE, SHOWING ENLARGED PILE CAPS, JOINTS, AND RAILING.

about 30 ft. long under the inner ends of the spans. The piles in the latter supports were encased above river level in pre-cast concrete tubes in the following manner. Steel tubes were used in the normal manner to bore the pile and when the required depth had been reached an 8-ft. length of 21-in. internal diameter pre-cast concrete tube was placed over the steel tube and fixed in line and level. The pile was then concreted in the normal manner, and the steel tube was withdrawn through the concrete tube and the latter filled with concrete. The piles under the river span are vertical, but those under the end spans are battered at 1 in 8 alternately inwards and outwards.

Certain difficulties at the site were overcome by the design. The presence of an existing structure made pre-cast piling undesirable, and the impossibility of lowering the water for more than a few hours weekly without excessive compensation to an adjacent mill owner had to be taken into account. Moreover, a good foundation of stiff blue clay was only available at a depth of not less than 16 ft. below ground level, and this condition, together with the high water-level previously mentioned, made it uneconomical to build a single-span bridge with solid abutments.

The work was designed by Mr. H. E. Lunn, B.Sc., A.M.Inst.C.E., County Surveyor of East Sussex, and with the exception of the piling, which was done by the Piling & Construction Co., Ltd., was carried out by direct labour. The cost of the widening was £2,000.

CUCKMERE BRIDGE, EAST SUSSEX

Three-span Bridge on Cast-in-Situ Piles.

THIS bridge (*Fig.* 49) spans the river Cuckmere below Horsebridge, and is situated on the Hailsham By-pass on the London–Eastbourne road (A22). It was designed by Mr. H. E. Lunn, B.Sc., A.M.Inst.C.E., County Surveyor of East Sussex, and is similar in design to Lindfield Bridge (see page 45), but is an entirely new structure. The spans are 16 ft. 6 in., 26 ft., and 16 ft. 6 in. and the width between the parapets is 110 ft. The slabs are 16 in. thick and the suspended part of the middle span is 18 ft. 6 in. long, and reinforced by 1⅛-in. longitudinal bars at 5½-in. centres and ⅜-in. transverse bars at 5½-in. centres.

In this case West-Rotinoff piles with 15½-in. and 17½-in. external diameters were used, and founded in blue clay about 20 ft. below ground level. The larger piles were used in the inner bents and the smaller piles in the outer bents. Their average lengths are 30 ft. and 25 ft. respectively.

The structure was built on dry land and the river was diverted through it afterwards, thus simplifying shuttering problems, as the soffit of the bridge is only 7 ft. above normal ground level, and the top of the bridge forms the road surface for vehicles. Great care was therefore necessary to prevent the possibility of settlement of the shuttering.

With the exception of the piling the work was carried out by direct labour. The cost was £5,000, including the wing-walls.

FIG. 49.—CUCKMERE BRIDGE.

Acute Skew Spans.

Two important road bridges have recently been completed for the Staffordshire County Council, and two more are shortly to be commenced. All were designed by the County Surveyor, Mr. Robert S. Murt, M.Inst.C.E.

Walton Bridge, over the River Trent.

A new bridge (*Fig.* 50) will be erected shortly over the river Trent at Walton, Stone, on a new road to be constructed by the Staffordshire County Council, passing to the south of Stone and linking route A51 with the Winchester–Preston trunk road (A34).

This bridge will be of the reinforced concrete tee-beam and slab type, with a square span of 38 ft. and a skew span of 40 ft. The width between parapets will be 82 ft. to accommodate dual carriageways each 22 ft. wide with cycle tracks and footways. The deck slab will be 8 in. thick reinforced with $\frac{5}{8}$-in. bars and the beams will be spaced at 5-ft. centres except under the pipe ducts. In section they will be 1 ft. 3 in. wide by 3 ft. 4 in. (gross) deep. The beams will have sliding metal bearing plates to cope with both lateral and longitudinal movement.

Warping of the beams due to lateral movement will be prevented by a reinforced concrete screen wall joining the beam ends over each abutment.

The abutments and wing walls will be of mass concrete, grooved and bush hammered on the face, and it is anticipated that a satisfactory foundation will be reached on a bed of hard gravel about 5 ft. below the river bed level. Reconstructed stone will be used in the pilasters and parapets which are of the open baluster type. The estimated cost of the bridge is £5,800.

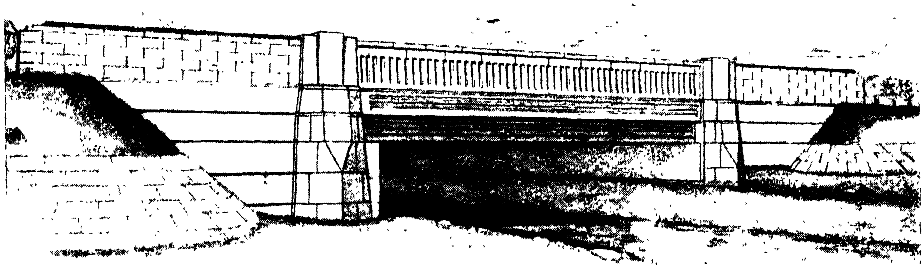


FIG. 50.—WALTON BRIDGE, STAFFORDSHIRE.

Standeford County Bridge.

Standeford County Bridge (*Fig.* 51), situated on the Wolverhampton–Stafford road (A449) ten miles south of Stafford, replaces an old five-span masonry arch structure with a width of 26 ft. between parapets crossing the Saredon Brook. The old bridge was abandoned on account of its awkward alignment, poor approach gradients, and narrow width relative to the requirements of the new structure, which will be 80 ft. between parapets. This will accommodate dual carriageways each 22 ft. wide with cycle tracks and footways.

The new bridge is a three-span reinforced concrete skew arch; each of the two outer spans is 18 ft. 1 in. and the middle span is 22 ft. 8 in. The arches on the outer spans are 9 in. thick at the crown and 12 in. thick at the haunches, and on the middle span 9 in. thick at the crown and $13\frac{1}{2}$ in. thick at the haunches. The main reinforcement is $\frac{5}{8}$-in. and $\frac{7}{8}$-in. bars in the middle span and $\frac{5}{8}$-in. bars in the outer spans.

The foundations, abutments, and piers are of mass concrete founded on red marl

about 5 ft. 6 in. below river bed level. The parapets are of hand-made sand-faced bricks with sandstone coping, and voussoirs of similar stone are provided in the facings to the arches. The wing walls, spandrels, and cutwaters are of mass concrete faced with sand-faced bricks.

The bridge is being erected in two sections in order to maintain a traffic route, and the construction of the second portion is now well in hand. The general contractors are Messrs. Orton & Dalby, and the total cost, excluding roadworks, will be about £7,400.

FIG. 51.—STANDEFORD BRIDGE (WITHOUT COPING).

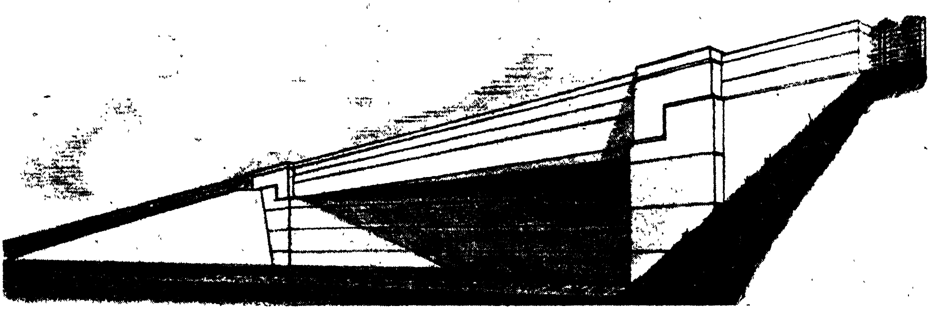


FIG. 52.—RODBASTON RAILWAY BRIDGE.

Rodbaston Railway Bridge.

Rodbaston Bridge is situated on the Wolverhampton–Stafford road (A449), eight miles south of Stafford, and will be replaced by a new bridge (*Fig.* 52), designed to carry dual carriageways, cycle tracks and footways over the main L.M. & S.R. line from Birmingham to Crewe.

The existing structure is a skew masonry arch with a width of 25 ft. between parapets, and is set at an extremely awkward angle in relation to the road approaches. Owing to its narrow width, awkward angle, and crown level, the old structure will be replaced by a new bridge, which will be 72 ft. 8 in. between parapets and have a clear span normal to the abutments of 28 ft. 1 in. and a clear skew span of 69 ft. 8 in. The headroom above the rail level will be 15 ft.

Owing to the very acute angle between the road and the railway (about 22 deg.) the abutments will be 188 ft. and 195 ft. long and the parapet girders 80 ft. and 88 ft. span, measured in each case between centres of girder bearings. As the bridge is located on a road curve with a tangent point at the crown of the bridge, the parapets are out of parallel. This accounts for the difference in lengths of the abutments and parapet girders. About 3,500 cu. yd. of mass concrete will be used in the abutments and wing walls. The

foundations will be carried down to sandstone about 7 ft. below rail level.

A deck of rolled steel joists encased in concrete has been adopted, having regard to the excessive skew, the restricted construction depth, and the necessity for providing a type of deck capable of rapid erection over the railway. Seventy-six 18-in. by 6-in. by 55-lb. steel joists 31 ft. long at 18-in. centres span normal to the abutments on the centre portion and fifty-five joists of diminishing lengths are framed to the plate girders of the parapets on each outside triangular corner of the deck. The minimum thickness of the concrete in the deck slab is 22 in. which provides for a 2-in. cover below the joists. Built-up steel plate girders 81 ft. and 89 ft. long and 6 ft. deep are provided at the parapets, and cast-steel pedestals will afford rocker bearings at each end. Provision will be made for expansion by means of phosphor-bronze strips in a steel bearing-plate under one of the pedestals to each girder.

The parapets will be formed by encasing the plate girders in specially-graded vibrated concrete heavily reinforced with ⅜-in. diameter bars, giving a 6-in. square mesh near the surface with the object of avoiding cracking due to shrinkage, temperature, or deflection. It is not anticipated that the live load will have any appreciable effect in this respect owing to the width of the side verges. The deck has been designed to take the Ministry of Transport loading with a maximum working steel stress in tension of 10 tons per square inch. The estimated cost, exclusive of roadworks, is £16,000.

The bridge will be commenced shortly and will be carried out by contract for the Staffordshire County Council subject to an agreement with the railway company.

New Bridge at Weston - on - Trent Level Crossing.

The erection of the new railway bridge on the A51 road at Weston-on-Trent, near Stafford, eliminates a dangerous level crossing on the L.M. & S.R. London to Manchester line. The danger was aggravated by the fact that the crossing is located at the junction of the Stafford–Uttoxeter road (A518) and the Lichfield–Stone road (A51) which carries heavy traffic between Lancashire and the south. The principle adopted in the scheme is to provide a through road for route A51 with a left-hand staggered crossing for route A518. The bridge over the railway is situated between the two junctions.

FIG. 53.—BRIDGE AT WESTON-ON-TRENT.

The new bridge (*Fig.* 53), which is completed, has a square span of 26 ft. 6 in. and a skew span of 44 ft. 9 in. A clearance of 15 ft. above rail level has been provided, and the bridge has a width of 50 ft. between parapets. The abutments and wing walls are of mass concrete faced with hand-made sand-faced bricks and the parapets are of similar finish.

The design of this bridge was complicated by the acute skew and the necessity for conserving every inch of construction depth. This has been overcome by providing four main built-up girders on the line of the skew with 18-in. by 6-in. by 55-lb. rolled steel joists set at 1-ft. 9-in. centres spanning normal to the abutments on the centre section of the bridge under the new carriageway.

The concrete deck slab has a minimum thickness of 22 in., which provides a

cover of 2 in. under the steel joists. Each of the four main built-up plate girders is 57 ft. long; the inside (or kerb) girders are 2 ft. 8½ in. deep; and the parapet girders 3 ft. 1½ in. deep. These girders are completely encased in concrete and are provided with sliding bearings at the free ends.

The bridge has been erected prior to the construction of the extensive new approach embankments, and the cost, exclusive of roadworks, is approximately £6,100. The bridge has been erected for the Staffordshire County Council by Messrs. G. Percy Trentham, Ltd., subject to an agreement with the railway company.

FOOTBRIDGE IN DERBYSHIRE

Arch Slab of 50-ft. Span.

A FOOTBRIDGE over the Wirksworth by-pass road, which is now under construction, is shown in *Fig.* 54. At the site of the bridge the by-pass road is in a rock cutting 40 ft. wide at the bottom, allowing for a 24-ft. carriageway and two 8-ft. paths.

The bridge, which was designed by Mr. C. G. Millican, County Surveyor of Derbyshire, and constructed by direct labour, is a segmental intrados arched slab with a span of 50 ft. 6 in. and a rise of 5 ft. 3 in. At the crown the slab is 8½ in. thick and at the springings 2 ft. 6 in. thick. The slab is 7 ft. 6 in. wide and the distance between the centre lines of the iron parapets is 6 ft. 2 in. The longitudinal reinforcement consists of thirty ⅞-in. bars at 6-in. centres in the top and the same number in the bottom. There is a clear cover of 2 in. of concrete on the top steel and 1½ in. on the bottom steel. Five-eighth-inch bars 7 ft. 2 in. long and at 7½-in. centres extend across the slab below the upper longitudinal bars and above the lower longitudinal bars. Three-eighth-inch stirrups at 6-in. centres enclose the longitudinal bars in groups of four, that is, two upper bars and two lower bars.

FIG. 54.

The abutments are 7 ft. wide by 6 ft. 8 in. deep and are stepped on the underside where they are in contact with a 10 to 1 concrete pier. On the front and sides the abutments are faced with random rubble. The arch and abutments were built with 1 : 1½ : 3 concrete, and a shrinkage gap 5 ft. long was left in the middle of the arch until most of the contraction during hardening had taken place.

THE new Waterloo Bridge over the river Thames has a roadway 58 ft. wide, two footpaths each 11 ft. wide and five spans each nearly 240 ft. clear. The bridge has been designed to carry the Standard Load for Highway Bridges of the Ministry of Transport, the equivalent loading curve being used. No reduction on account of the six-line width of roadway was made. In addition, the design of the cross girders and deck slab was controlled by the assumption of a 40-ton axle load (two wheels of 20-tons each, including impact) or a special lorry on multiple wheels having a gross weight of 150 tons including impact allowance.

The main members throughout are of reinforced concrete. Fabricated steel work has, however, been used for details, such as those at expansion joints and for the inclined struts to the pier shells, wherever it was advantageous.

The relation of the primary structural elements is shown diagrammatically in *Fig.* 60. Changes in length are taken care of by expansion joints, which also permit of angular movement in a vertical plane. A simple knuckle joint is provided at the bridge end of the approach slab so that changes in level and slope of the cantilever are accommodated by the hinge action of this slab. The suspended portion of the centre span is similarly adapted by the expansion joints at its ends. The bearing walls of the piers and abutments, by reason of their flexibility in the direction of the bridge, offer little restraint to horizontal movement and change of slope of the superstructure, and so constitute in effect an articulated support.

FIG. 55.—THE UNDERSIDE VIEWED FROM VICTORIA EMBANKMENT.

Piers.

The pier construction is shown in *Fig.* 57. The foundation consists of a solid block of concrete 6 ft. thick, reinforced at the bottom with transverse and longitudinal bars. Alternate bar-ends are welded to the steel sheet piling, and welded anchors are also provided near the top of the block, thus effectively securing the piling against relative movement. The reinforcement has been designed to suit the bending stresses resulting from the excess of upward over downward pressure on the footing projection and from the skin frictional support afforded by the piling.

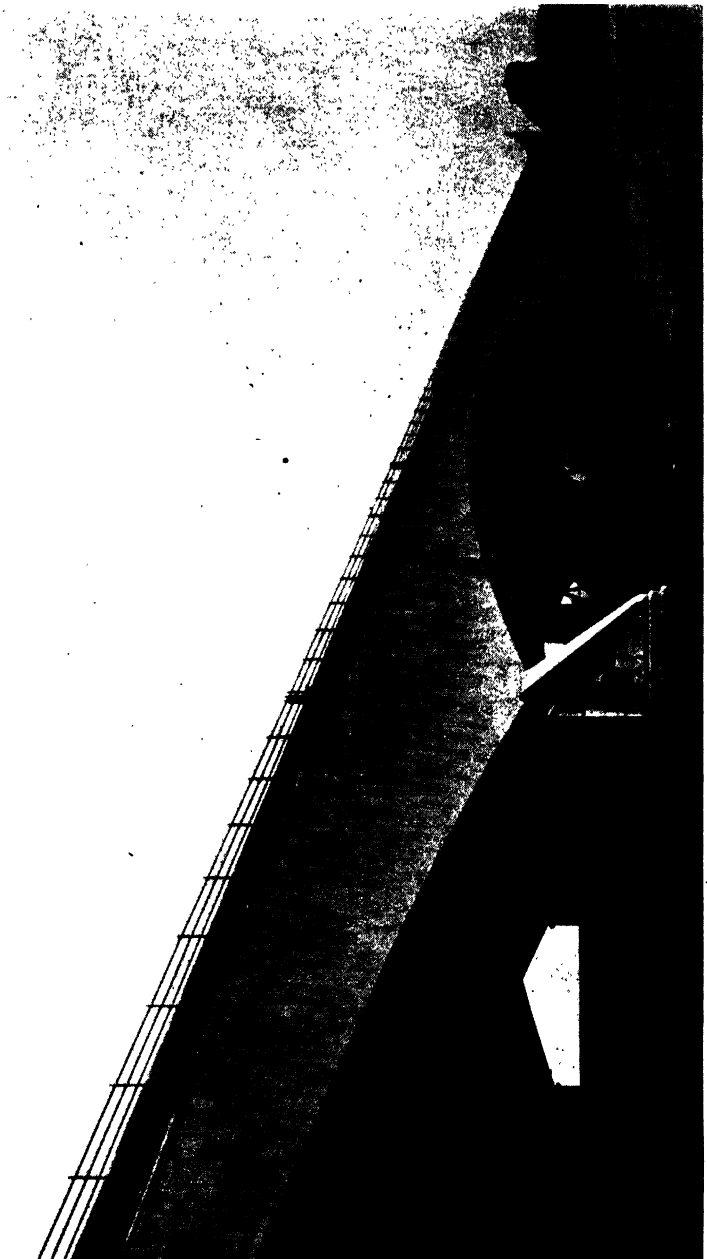


Fig. 56.—The New Waterloo Bridge: View from Upstream.

Projecting bars are cast into the foundation to bond with the cellular base to the bearing wall and pier shells.

The cellular base is provided to spread transversely the load from the bearing wall, and to form a transition between the solid block and the narrow wall. The reinforcement to the cross walls of the base has been arranged to take the principal tensile stresses arising from this action.

The bearing wall carries the whole

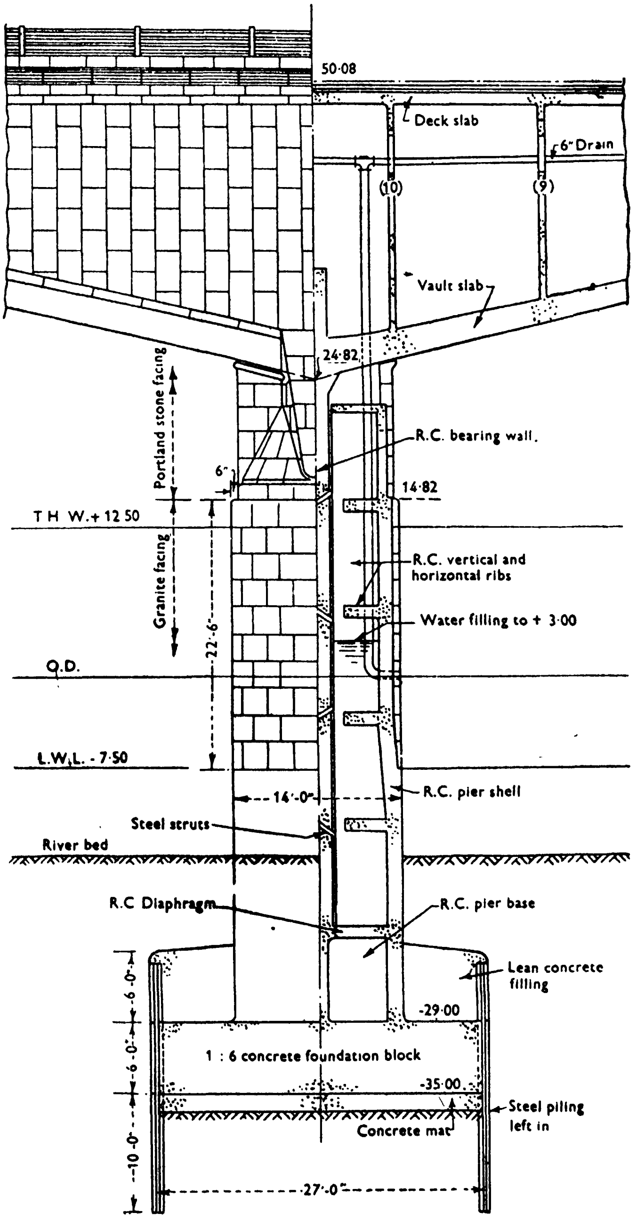


FIG. 57.—DETAILS OF PIER.

weight of the superstructure and, in addition to the direct stress resulting therefrom, is subject to flexural stresses due to the various movements. The wall is rigidly connected to the cellular base and the superstructure and serves to fix the main box members against torsion; it also distributes the loading longitudinally over the foundation and lends itself to a convenient scheme of jacking. The lower portion of the wall is comparatively lightly reinforced, whilst the upper portion, above the jacking gap, is heavily reinforced, particularly under the inner ribs of the superstructure; in this region transverse reinforcement in the form of bars welded at their ends to the vertical and the longitudinal horizontal bars is also provided. The proportion of direct stress to bending stress is such that tension cannot occur in any portion of the wall.

The bearing wall is surrounded by, but completely separated from, a granite and Portland stone faced reinforced concrete shell. This shell, apart from appearance, protects the main supporting member from damage by shipping, provides the substance of the stops preventing excess movements of the superstructure, and constitutes a permanent cofferdam which would, if necessary, facilitate inspection and repair of the bearing wall.

The vertical ribs on opposite sides of the bearing wall are connected by steel diagonal members passing through clearance holes, thus forming in effect a truss the full width of the pier to resist impact and forces applied at the stops. The steel diagonals, where not embedded in the rib concrete, are protected against corrosion by zinc spraying and "gunned" bitumen.

The stops at the top of the vertical ribs are opposed to the haunch of the bearing wall. Design to resist traction forces only presented no difficulty, but it was thought desirable to develop, if possible without any great additional cost, the full strength of the shell construction (its scantlings being as determined by its other functions) in resisting indeterminate forces such as might be occasioned by an exceptionally heavy impact deflecting the shell against the superstructure. The solution was seen in developing the maximum possible friction between the haunch and the stop so that virtual A-frames would be set up by the bearing wall and the ribs resisting pressure. Experiment showed that with concrete cast against hardened concrete and separated after setting, a friction angle of about 45 deg. was developed on further contact. The stops at piers Nos. 1 and 4 were therefore formed by pouring them against the roughened haunch, the superstructure being jacked over as necessary. At piers Nos. 2 and 3, where clearances are greater, it was inconvenient, in relation to the contractor's programme, to jack over the superstructure, and the stop faces were formed by a slab of hard Portland stone fitted to the haunch and then drawn away and cast into the stop.

The design of the abutments is generally on similar lines to that of the piers, but no stops are incorporated in the shell structure.

Main Girders.

The superstructure consists throughout of two box girders, subdivided by internal ribs and diaphragms, carrying a central strip of decking which is integral with the main members. Considered longitudinally, the bridge is symmetrical about its centre and each half consists of a twin two-span girder continuous over the first river pier (pier No. 1 or pier No. 4) and cantilevering shorewards from the abutments and into the centre span from the second pier. The gap in the centre span, between the cantilevers extending from the north and south, is filled by a suspended section, whilst each shore end cantilever carries a short span approach slab.

A cross section of the girder at the crown is shown in *Fig.* 58. The lower flange is comprised by the curved vault slab 25 ft. wide. The web member is made up by four ribs, the inner being about double width throughout compared with the others; the upper flange is formed by the deck slab.

The moment of inertia was calculated at ten sections on the span and the analysis was carried out by ordinary slope-deflection means. It was decided to consider the full concrete section as acting, but with a varying modulus of elasticity for concrete. On the compression side the full value was taken from the extreme fibre to the neutral axis, except near the centre-line of the deck, whilst on the tension side the modulus was assumed to vary parabolically from the full value at the neutral axis to half value at the extreme fibre. The reinforcement (tension and compression) was taken into account at the appropriate modular ratio. The central

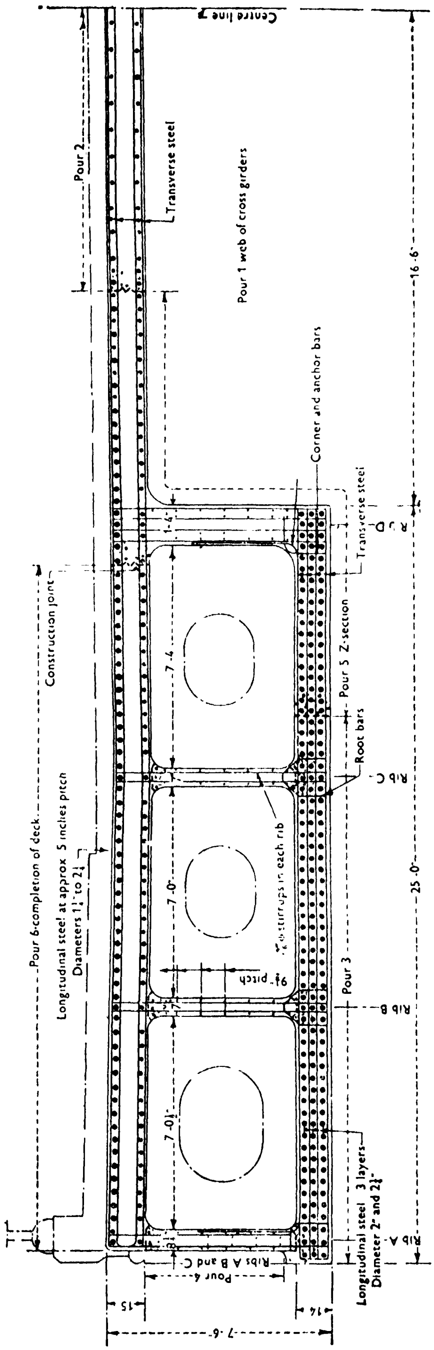


FIG. 58.—HALF CROSS SECTION AT CROWN.

portion of the deck slab, being monolithic with the box members, will act with them, but near the centre line, owing to shear strain, the full stress will not be developed, and to allow for this the slab depth and steel area at the centre were taken at half value, increasing uniformly to full value at a point 4 ft. from the inner face of rib D. A modulus value for concrete of $E = 4{,}500{,}000$ lb. per square inch was taken for live load effects, and of $E = 1{,}800{,}000$ per square inch for dead load moments and deflection. The initial deflections on jacking showed $E = 5{,}500{,}000$ lb. per square inch approximately, whilst subsequent creep deflections indicate $E = 1{,}800{,}000$ lb. per square inch to be about the correct asymptotic value.

Longitudinal reinforcement in the deck and vault consists of straight bars only, their number and sectional area being varied to suit the bending moment. Shear reinforcement is generally in the form of transverse bars, but in the ribs horizontal shear steel is also used. Stirrups and transverse bars are generally at constant pitch, diameters of bars being adjusted as necessary.

The cross girders carrying the deck slab between the main members are of T-beam type. The external dimensions were determined by architectural considerations, and the webs were made hollow to avoid unnecessary weight.

Cantilevers and Suspended Span.

In the case of the shore cantilever the negative bending moment at the abutment resulting from its self-weight was insufficient to reduce the positive moment near the centre of the first span to a practicable value. Considerations of the effect of relative settlement of supports showed it to be undesirable to anchor down the end, as the additional span thereby introduced would be too short. It was decided, therefore, to load the end of each member with kentledge, and 270 tons of cast iron were provided in a special box at each corner of the bridge.

Calculations showed the ideal length of the suspended span to be 88 ft. This length, however, would have caused the joint to clash with a cross girder and diaphragm, the uniform pitch of which it was not desired to upset; the suspended length was therefore increased to about 94 ft., and to preserve the "balance" at the adjacent piers 40 tons of kentledge

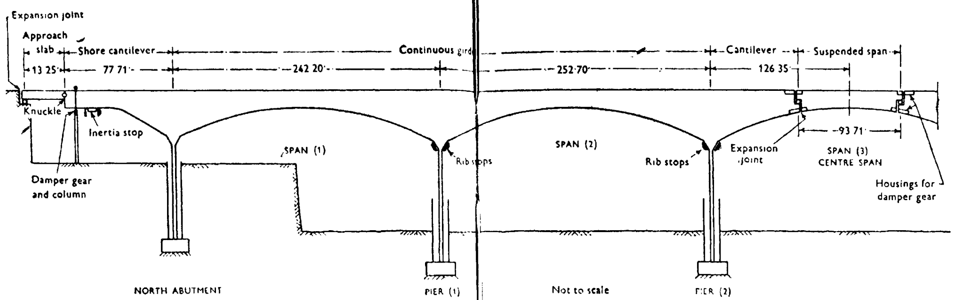


FIG. 59.—ARTICULATION DIAGRAM.

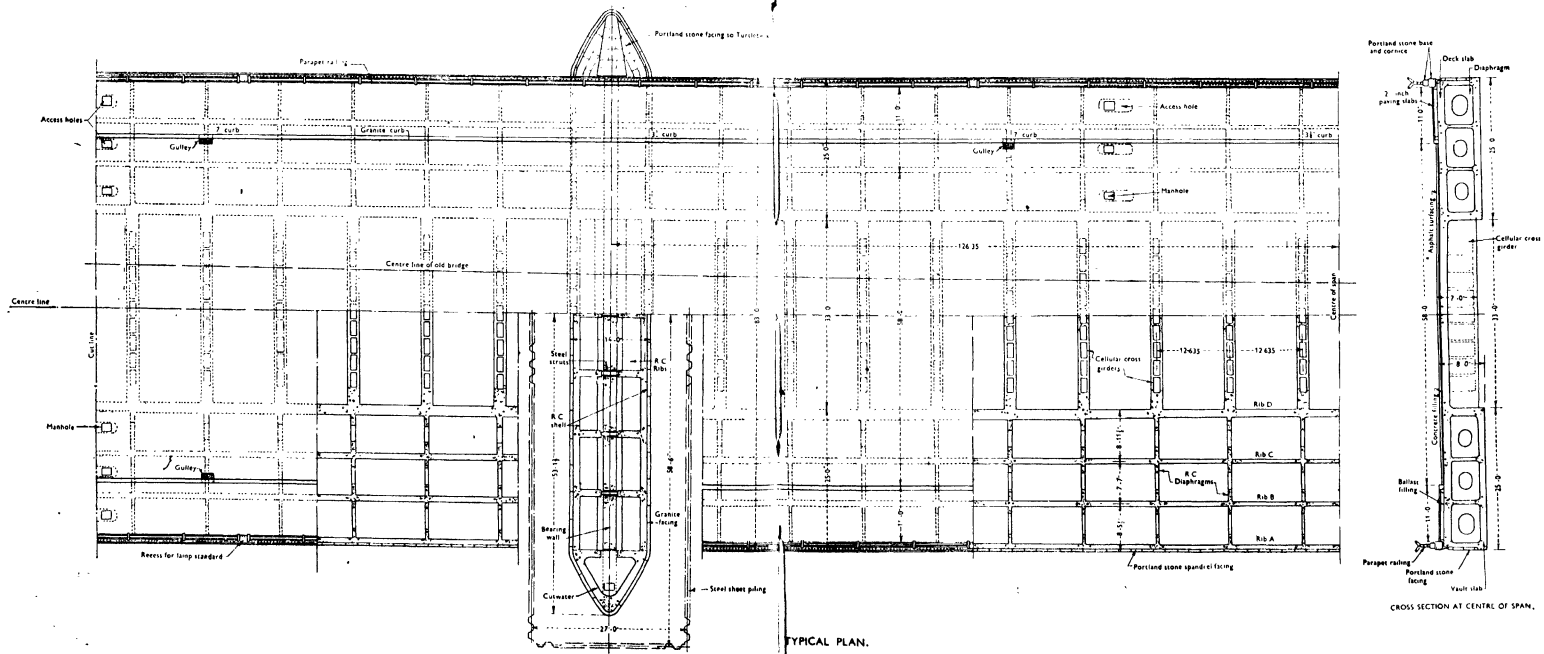


FIG. 60.—STRUCTURAL ARRANGEMENT.

FIGS 13.

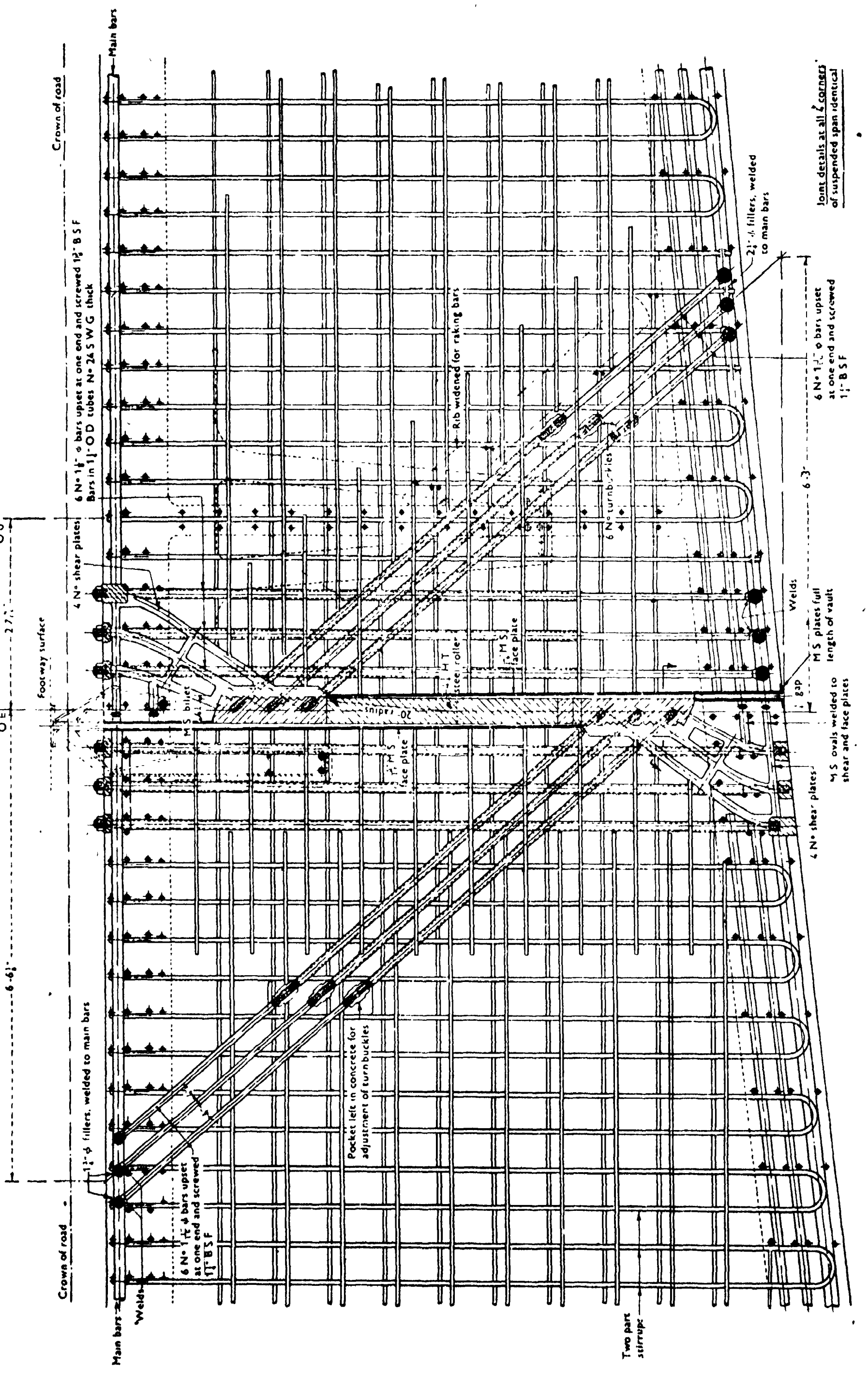


FIG. 61.—TYPICAL RIB DETAILS, CENTRE SPAN.

were provided inside each cantilever member near the joint.

Torsion.

By reason of the disposition of the loading on a cross section of the superstructure and the comparative flexibility of the cross girders, the main box members are subjected to torsion. In computing the value of this, together with the degree of fixity at the ends of the various cross girders, a first assumption was made that the shape factor for torsional rigidity for a hollow box member with an eccentric core was as given by St. Venant for a solid rectangular member of similar external proportions. To confirm this assumption, and to obtain the relation between the shear and flexural moduli of the concrete, experiments were made on both solid rectangular specimens and twin hollow specimens of the mean proportions of the bridge members, with wall thicknesses to scale. All specimens were of the same concrete mix as the bridge members and were carefully vibrated during manufacture. The box specimens were tested with and without a connecting slab simulating the strutting action of the deck slab. Bending tests were also made. It was found that the shape factors for solid and hollow specimens were practically identical; the shear modulus was two-fifths of Young's modulus (that is, for the very high-grade concrete used, a Poisson's ratio of 0·25 obtained as for steel). The torsional rigidity was the same whether or not the members were strutted, and, by test to destruction, it was confirmed that the greatest shear stress occurred in the thinnest wall independently of its distance from the centroid of the section.

Expansion Joints.

At the extreme ends and in the centre span at the bearings of the suspended section, expansion joints are provided. All joints are of the single segmental roller-bearing type, and they are arranged to cater for a total change of length of 6 in., corresponding to a range of body temperature of 60 deg. F. The centre span joints have several features worthy of mention (*Figs.* 61 and 62). It was necessary to avoid projections at the joints, and the main rollers were therefore limited in width to the thickness of the ribs. Loading conditions were such that, using medium high-tensile steel, a diameter of 40 in. was required for the rollers, and this, together with the inevitable division of the rib depth, so reduced the corbel above and below that a shear value in excess of 1,000 lb. per square inch was called for. Such a high figure could not be realized with normal reinforcing; accordingly the principal compression component was transferred from the bearing billets by means of special reinforcement, or "shear" plates, whilst the principal tensions were taken care of by medium high-tensile bars which were pre-stressed as described later.

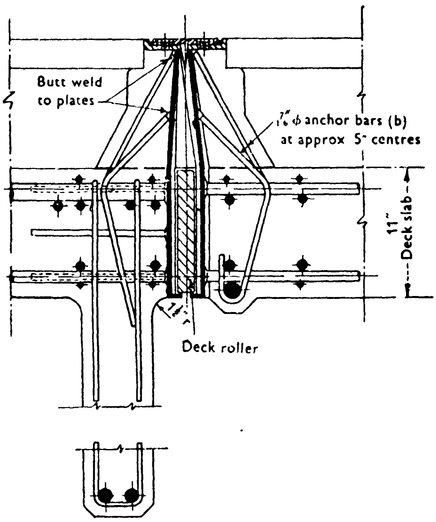


FIG. 62.—SECTION OF JOINT IN DECK.

Considerations of transverse deflection showed that, with the main bearing rollers only, the major portion of the loading would be thrown on to the inner rib. Although this action could have been compensated to a large extent, in the case of dead loading, by the initial setting, the greater live load effect could not conveniently be eliminated. Secondary rollers in the deck and vault slab were therefore provided which ensured the transmission of the torsion arising from transverse deflection across the joint, and the whole span was thus enabled to act in relation to torsion as if monolithic.

Stops.

At the top of the vertical ribs of the pier shells and near the end of the shore cantilevers, stops are provided to limit the

movements of the superstructure resulting from various causes. The stops at piers Nos. 1 and 4, being practically at the centre of expansion of the north and south halves respectively, are provided with only ⅛-in. mean clearance each side; those at the other piers and the end stops have about ⅜-in. mean clearance, the amount being adjusted so that contact is made, one side or the other, at the extremes of temperature. The end stops consist of heavy reinforced concrete walling, founded generally on cored piles, and are of such robust construction that should any pier develop a tendency to tilt sufficient resistance would be available for prevention or correction. The stop detail is comprised of an elongated steel-shod nib projecting horizontally from the vault slab of the cantilever into a steel-lined recess in the walling. In addition to the stops described, ties are arranged across the centre span expansion joints to limit independently the amount by which they may open.

Should the bridge ever be called upon to carry its full design load there would be, in the absence of preventive means, first a downward and then an upward deflection of about 1 in. at the end of the shore cantilever as the load passed over and on to the first span. This would cause damage to the road and footpath surfacing at the approach and might give rise to an undesirable feeling of deflection. Dampers were therefore provided in the form of reinforced concrete columns containing a central rod which passes through a hole in the vault slab. Adjustable stops were formed between the top of the column and the vault to limit downward deflection, and between a pad on the top of the vault and a nut at the end of the rod to limit upward movement. These dampers were so proportioned that whilst their strength was adequate to control live-load deflections they would yield before any damage to the bridge structure proper could result from failure to readjust their setting following an appreciable settlement of the abutment or pier foundations.

Construction Joints.

The desirability of avoiding joints in zones of high shear stress, the effect of the settlement of centering piles during construction, and the contractor's scheme for carrying out the work had to be taken into account. The arrangement finally evolved (*Figs.* 58 and 61) consisted in providing temporary transverse gaps at about one-sixth span from the piers and at the centre, thus dividing each span-length into three sections, one pier section, and two centre sections, each capable of slight relative settlement during concreting. The sections were sub-divided by longitudinal joints in pre-determined positions, to give reasonable pours without introducing additional transverse joints, except as afforded in the centre span by the expansion joints.

It was required that throughout the bridge the webs of the cross girders should be the first pour, followed generally by a central strip of deck slab. The pier section was to be poured in the sequence: vault, ribs (in three lifts), and deck. The centre sections were to follow the order: outer 18-ft. width of vault, three outer ribs (in one lift), inner rib together with the remainder of the vault and the deck connecting it to the central strip (**Z**-shape pour), and finally the outer portion of the deck slab. The temporary gaps were permitted to be closed on completion of the adjacent sections and the substantial completion of the next sections.

Pre-Stressing.

In the shore cantilevers, at the top of the bearing walls, and in the vicinity of the centre-span expansion joints, where exceptionally high shear stresses obtained, certain reinforcing bars were required to be pre-stressed. Such bars were of medium high-tensile steel with ends upset and screwed, and contained in steel tubes fitted with projecting end connections. After the concrete had been poured and had hardened the bars were stressed by passing steam through the tubes and taking up the thermal extension by turning the end nuts or turn-buckles so that, on cooling, the required stress was induced. A final stress of 30,000 lb. per square inch was required in the bars, and the initial apparent stress, as measured by the turns of the screws, to ensure this was found by calibration with a hydraulic jack to be 45,000 lb. per square inch, the difference being due to elastic and creep compression of the concrete and to shrinkage, the latter factor being small on account of the concrete being many months old when stressing was carried out. The bars were finally

grouted up solid in the tubes, the steam connections being used for this purpose.

Welding.

To realize the desired slimness of the construction a high percentage of reinforcement was necessary, and it was evident that welding would afford many advantages. The elimination of laps, splice bars, and hooks would enable scantlings, and therefore dead weight, to be reduced to the minimum, and within the limitations of the design would permit the simplest arrangement of the steel in relation to concrete placing. Welding also offered a rigid reinforcement cage true to dimensions and cover and resistant to displacement during concreting, and provided a means whereby efficient crack-control could be ensured. Electric arc welding was used.

Concrete.

The superstructure, the bearing walls, and the cellular bases to the piers and abutments were specified to be of concrete quality A, the mix being: Cement, 112 lb. minimum and 140 lb. maximum; aggregates (sum of volumes measured separately), $5\frac{5}{8}$ cub. ft. Strength requirements on 6-in. cubes were: Preliminary tests at 28 days, 5,600 lb. per square inch; works tests at 28 days, 4,200 lb. per square inch, and at 3 months 5,000 lb. per square inch.

The pier and abutment shells were of concrete quality B, which mix was similar to quality A but with strength requirements reduced by 20 per cent. In practice it was found that the strengths corresponding to quality A could be realized with the minimum quantity of cement, so that the mixes became, in fact, identical. Generally for vibrated reinforced work a slump of 3 in. was permitted. Concrete with 1-in. slump was used in many heavily-reinforced parts of the work, and there was no evidence to show that a higher value was generally necessary. The water/cement ratio ranged from 54 per cent. to 60 per cent. by weight.

The whole of the concrete in the bridge structure, except the foundation block, was vibrated, a minimum frequency of 5,000 cycles per minute being specified. Electric vibrators, of 160-watt and 250-watt capacity, clamped to the shuttering, were used generally. Immersion vibrators were employed in situations such as at junctions of members where the external machines could not be fully effective.

Surface Treatment.

No treatment could be adopted which would impair the strength and life of the structure, and accordingly bush hammering and tooling, which not only remove the surface but also cause damage to the underlying concrete, were excluded from general adoption. The stone facing has been arranged in vertical strips so that the joints in no way imply heavy stones functioning as an arch or wall. It was specified that the forms for surfaces exposed to public view should be lined with a smooth-faced non-absorbent plywood and, after stripping, the concrete face should be mechanically ground by carborundum disks. The "arch ring", where special cover to the reinforcement had been provided, was lightly hammered with an electric hammer, whilst the underside of the structure, except the curved vaults of the end spans, received an "engineering" finish, consisting of grinding down the worst board marks and blemishes resulting from welding splash, cleaning, and then stippling with and rubbing in a thin coat of neat cement mortar. The end span vaults were lightly sandblasted in two stages, the first to expose flaws for making good and the second an all-over treatment to give a uniform texture.

Stresses.

The maximum values of stresses in the reinforced concrete construction were broadly governed by the desire to provide factors of safety equal to those implicit in the Code of Practice, Section 3. The concrete generally corresponded to the nominal 1 : 1·5 : 3 Special Grade mix; the reinforcement was generally mild steel, but medium high-tensile steel was used for pre-stressed bars. The maximum working stresses are given in *Table* I. Preliminary and works crushing tests on 6-in. cubes at 28 days called for minimum strengths of 5,600 lb. per square inch ($4x$) and 4,200 lb. per square inch ($3x$) respectively. The compressive stress in the main girders, although a bending stress, was limited to the mean of the bending and direct values on account of the cellular form of these members. The shear on a reinforced section was limited to the value given (the Code would permit 550 lb. per square

inch) for reasons of crack control. The figure was arrived at as a result of tests to determine the ultimate tensile strength of the concrete in bending and shear. A general minimum of 450 lb. per square inch was found from both bending and torsion tests on unreinforced specimens.

The flexural reinforcement to the main girders consisted generally of bars about 2 in. diameter; tests showed a yield-point of 36,000 lb. per square inch for this size of bar, so that to preserve the normal factor of safety (about 2·2), which is based on the yield-point of smaller diameter bars, the working stress was reduced.

In the superstructure the calculated maximum stresses correspond closely to the working stresses given in *Table* I, except in the case of bond, where the maximum stress, computed in the ordinary manner, amounts only to 70 lb. per square inch. The bearing pressures on the foundations are given in *Table* II. The figure of 8 cwt. per square foot for the skin friction on the piling, taken on the projected area, is given as a probable mean value. On first loading the friction would be some 50 per cent. higher, but as a result of shear "creep" in the clay there would be a transference of load to direct bearing, and the ultimate value would be small.

Messrs. Rendel, Palmer and Tritton were appointed engineers in association with Sir Peirson Frank, M.Inst.C.E., chief engineer of the London County Council. Sir Giles Gilbert Scott, R.A., was the collaborating architect, and Messrs. Peter Lind & Co., Ltd., were the contractors. The foregoing notes are from a paper read by Mr. E. J. Buckton, B.Sc., M.Inst.C.E., and Mr. J. Cuerel, B.Sc., M.Inst.C.E., before the Institution of Civil Engineers.

TABLE I.

Concrete stresses: lb. per square inch		Steel stresses: lb. per square inch	
Bending	1,400(x)	Beam tension	16,500
Direct	1,100	Web ,,	18,000
Main girders	1,250	Pre-stressed bars	30,000
Shear	140	Compression	Modular ratio basis
Bond	140		
Shear (reinforced)	450		

TABLE II.

ABUTMENT.

Skin friction on piling	Gross pressure: tons per square foot	Net pressure: tons per square foot
Nil	4·76	2·54
8 cwt. per square foot	3·77	1·55

PIER.

Skin friction on piling	Gross pressure: tons per square foot	Net pressure: tons per square foot
Nil	4·45	3·12
8 cwt. per square foot	3·68	2·35

BRIDGES IN CORNWALL

THREE interesting bridges are being built by the Cornwall County Council, two on the road diversion at Lostwithiel and one on the Redruth by-pass road.

The diversion at Lostwithiel will provide a highway 50 ft. wide to take main road traffic off the fifteenth-century masonry bridge and away from the level crossing on the Great Western Railway Company's main line. As the road is curved throughout both bridges are on the skew. Trial holes were dug on both banks of the river Fowey and on both sides of the railway, and although the sites are near to each other the strata are entirely different. Geological investigations proved that a fault exists right along the valley.

River Bridge at Lostwithiel

The river bridge is built on a good gravel foundation and has three spans, two of which provide the waterway and the third is a cattle-creep connecting the severed portions of the farm-land. The main span has a square measurement of 45 ft. and the side spans are both 15 ft.

In the design attention was given to the proximity of Restormel Castle and the cutwaters are extended upwards as semi-circular towers; the bridge is also faced with grey granite rubble masonry. The voussoirs are properly cut and built as skew masonry arch stones.

The shapes of the foundations are different because the side spans are at different levels. On the west it was necessary to incorporate the pier in the abutment; on the east the 15-ft. span has two hinges and is merely supported on the back of the abutment of the main opening (*Fig.* 63). It is unfortunate that in order to economise in the cost of the approaches the main arch is so flat, but the bridge has only to carry the road over the waterway and the arch was designed for these conditions. The rise of the vault is 6 ft. 6 in. and the thickness at the crown 1 ft. 5 in. Because of its small rise and elliptical shape the rate of thickening of the vault towards the springings required considerable care in order to keep to the working stresses of 750 lb. per square inch in the concrete and 16,000 lb. per square inch in the steel. To reduce as much as possible the initial stresses due to shrinkage, keyways are to be left at 3 ft. 6 in. from each abutment and will be filled in two weeks after the portion at the crown of the arch is concreted.

Special attention is given to the concrete; the proportions are 1 : 2·18 : 3·57 for the abutments and 1 : 1·89 : 3·36 for the arches, and test cubes give average strengths of 3,950 lb. per square inch and 5,210 lb. per square inch. Ordinary Portland cement is used in the first mix and rapid-hardening Portland cement in the second.

Fig. 65 shows the reinforcement at the extrados of the main arch and vertical steel at the face of the pier. The view of the bridge from the west side (*Fig.* 66) shows the shuttering of the small river span in the foreground.

About half of the work is completed and satisfactory progress is being made to finish the work within the specified time of one year.

Railway Bridge at Lostwithiel.

Trial holes showed that the ground is composed of a thin layer of surface soil on poor quality china clay. The total depth of this clay was not reached in the trial holes, but as low as 27 ft. below the railway lines the same material was found. Comparison of the surface levels with those at the river indicated that gravel might be reached at a depth of 35 ft., and it was assumed that piles 35 ft. long would be required.

The railway company stipulated that the piles had to be driven without shock in order that the track should not be affected. Some form of in-situ piling was therefore necessary, but the actual type was left to the contractor subject to its being approved by the County Surveyor. The specification called for in-situ piles to withstand a working load of 45 tons and a trial load of 60 tons. François bored piles were adopted by the contractor and have proved successful. The piles are 15 in. in diameter, reinforced with six ⅝-in. bars, and have an average length of 38·7 ft. So far four tests have shown very slight reductions in levels, some of which were due to the elastic compression in the piles.

During the piling operations the surface

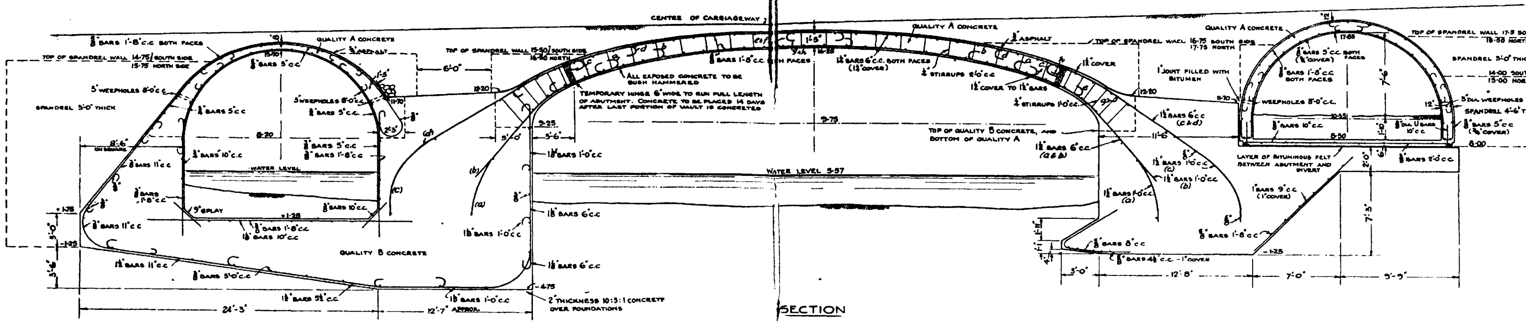


FIG. 63.—RIVER BRIDGE, LOSTWITHIEL, CORNWALL.

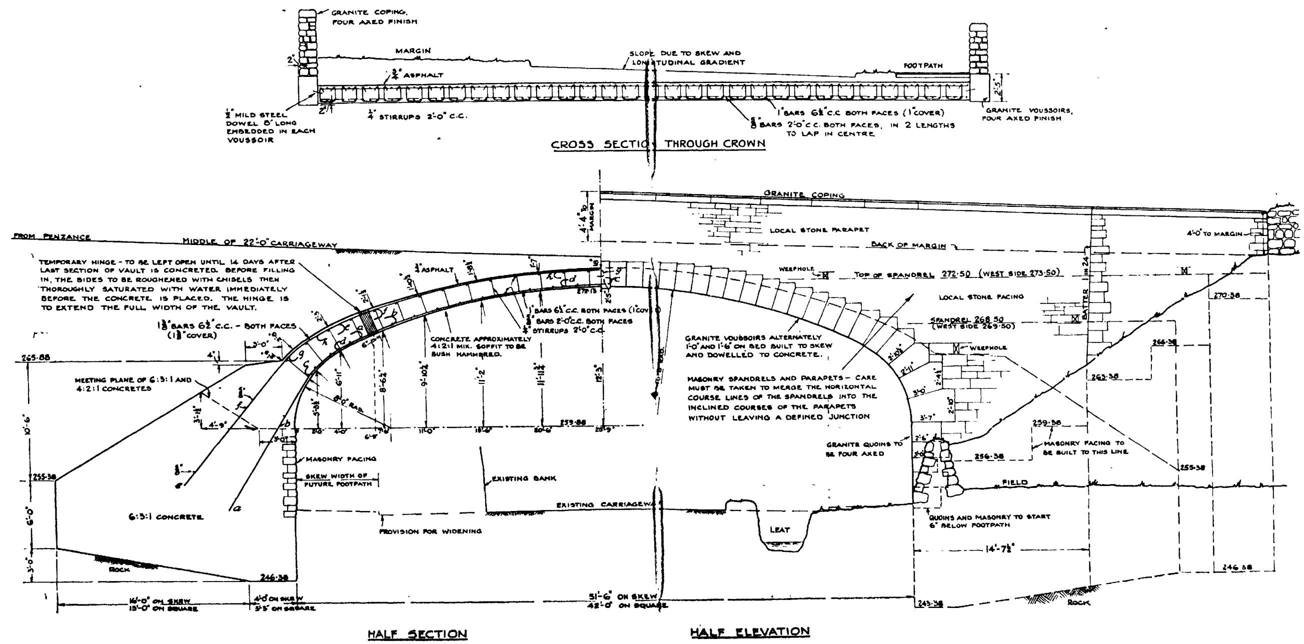


FIG. 64.—TOLGUS BRIDGE, CORNWALL.

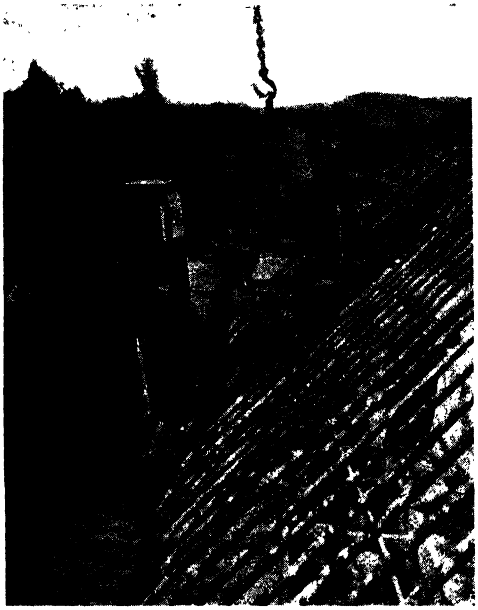


FIG. 65.—CONCRETING MAIN ARCH.

FIG. 66.—SHUTTERING FOR SMALL RIVER SPAN.

of the ground became saturated with water and made working conditions very bad, and before the foundation slabs could be commenced it was necessary to excavate the surface soil and consolidate the top of the clay with 12 in. of ashes. Earth thrusts behind the abutments and wing walls could not be resisted by such ground, consequently raker piles at 65 deg. were provided and, in addition, a deep toe-beam was designed for the front of the foundation slab.

In the design an effort was made to provide a more pleasing elevation than is obtained by the use of horizontal beams and decking. There are three skew spans, each covering two tracks—the square measurements of the outer spans are 30 ft. and the central span is 28 ft. 6 in.—of solid continuous slab design with 6-ft. splays at the supports. The slab is 1 ft. 9 in. thick in the central portions and 3 ft. 3 in. thick at the abutments and piers; it is continued beyond the parapets to form the smoke canopy. To protect the concrete soffit from the engine fumes it is to be painted with two coats of bituminous paint. Provision for expansion and contraction of the slab is made over both abutments by rustless steel plate bearings.

The contractors have devised a method of supporting from above the shuttering of the decking and casting strips continuous over the three spans, intermediate strips being supported from those already concreted.

Messrs. Aubrey Watson & Co., Ltd., are the contractors for the two bridges at Lostwithiel.

Tolgus Bridge, Redruth By-Pass Road.

This is an arched bridge (*Fig.* 64) to take the by-pass road over an existing road. The skew span is 51 ft. 6 in. and the square span is 42 ft. The bridge is to be faced with masonry and the granite voussoirs will be designed and built to suit the skew. The soffit of the vault will be bush hammered. As for the Lostwithiel bridges, a coloured elevation of the proposed structure was submitted to the Royal Fine Art Commission. No alteration was made but it was suggested that lime mortar should be used when the masonry is built. From previous experience of the Commission, no string-course is provided, although the courses of the masonry are horizontal up to the margin of the by-pass road and then inclined parallel to the gradient. So as to prevent an ugly junction of these course lines careful building of the masonry will merge the horizontal into the inclined lines in two or three courses well broken up by jumpers. The same arrangement is necessary at Lostwithiel and the change is quite unnoticeable.

Trial holes were excavated and solid rock was reached at convenient levels and no difficulties should arise when the foundations are concreted.

The design of the arch gave some trouble, and in order to provide the requisite headroom and to adhere to the longitudinal gradient of the new road over an elliptical shape was adopted. Ultimately a three-centred arch slightly varying from the ellipse was found to have considerably smaller temperature stresses and was incorporated in the working drawings.

The bridge will be built by direct labour at an estimated cost of £8,000.

The river bridge at Lostwithiel and the Tolgus bridge were designed in the office of the County Surveyor. The railway bridge was designed by the Indented Bar & Concrete Engineering Co., Ltd., from eighth-scale plans also prepared in the County Surveyor's office. The works are being constructed under the jurisdiction of the County Surveyor, Mr. E. H. Collcutt, A.M.Inst.C.E.

DOG LANE BRIDGE, NEASDEN

Pre-cast Arch Ribs.

THE portion of this bridge which carries the North Circular Road over the London & North Eastern Railway Company's main lines and sidings has recently been widened by 40 ft. in accordance with plans prepared by Mr. V. A. M. Robertson, M.Inst.C.E., Chief Engineer of the London Passenger Transport Board. The contractors were the Cleveland Bridge and Engineering Co., Ltd.

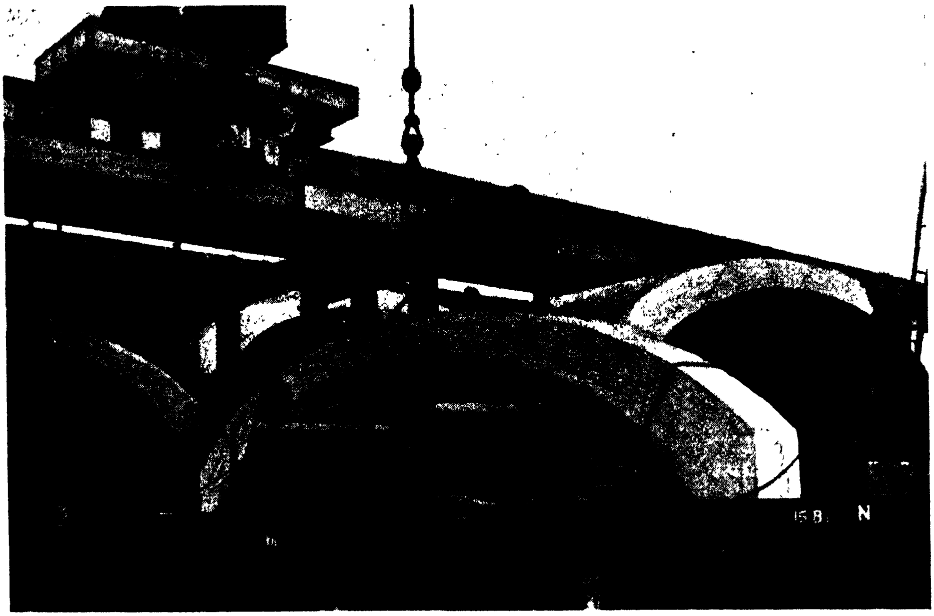


FIG. 67.—LIFTING RIBS INTO POSITION.

In three of the five spans the widening has been carried out in brick arches on brick-faced mass concrete piers, but the construction of the two spans over the sidings and main lines was executed with pre-cast reinforced concrete arches on account of it being impossible to erect the usual type of centering and falsework. The span over the main steam lines is 28 ft. 2 in. and over the sidings the span varies from 26 ft. 9 in. under the existing bridge to 28 ft. 9 in. at the outer end of the extension, the variation being due to the curvature of the permanent way.

In the width of the extension of each span there are thirty-eight pre-cast ribs 1 ft. wide by 1 ft. 6 in. deep at the crown, each being reinforced by four $\frac{9}{16}$-in. Isteg bars in both the top and bottom and placed at 3 in. from the intrados and extrados of the rib. The ribs have a horizontal bearing 2 ft. wide on each pier, and were designed for permissible stresses of 600 lb. per square inch compression in the concrete and 16,000 lb. per square inch in the reinforcement. The proportions of the concrete were 1 : 2 : 4 and rapid-hardening Portland cement was used.

To avoid making a large number of ribs with varying radii to meet the changing span over the sidings, the circular haunches of the ribs were designed of constant shape and the variation in span was procured by inserting a portion at the crown of the rib whose length could be adjusted as required by cutting short the mould in which the ribs were cast.

Each rib weighs about 10 tons, and was lifted at two points 5 ft. on either side of the crown by a crane travelling on a steel

FIG. 68.—ASSEMBLED REINFORCEMENT WITH MOULDS ON THE LEFT.

gantry supported on the mass concrete piers (*Fig.* 67). Views showing the casting of the ribs are given in *Figs.* 68 and 69. The eye-bolts for lifting the ribs were attached to a rolled steel joist spreader suspended from the crane. The spandrel walls were faced with brickwork and the parapet was also constructed in brickwork.

FIG. 69.—CASTING THE RIBS IN VERTICAL PLANES.

Friars Bridge.

THE original Friars Bridge was a brick arch with Kentish Rag spandrels, and up to the time of its demolition was in a state of good repair. It required, however, to be strengthened to make it capable of carrying Ministry of Transport loading, and it would also have needed widening to conform with road improvements.

It was found impracticable to strengthen the existing structure, and a new bridge (*Fig.* 70), was designed on the rigid-frame principle, although in appearance it is an arch similar to the original bridge. The spandrels have been faced with Kentish rag and the brick parapet is also in keeping with the previous bridge. The span of the bridge is 28 ft. 3 in. Provision was made for a future deepening of the river bed, and this introduced some difficulty in the construction of the foundations because it was necessary to excavate through a layer of gravel into silt of poor bearing capacity extending to a considerable depth. Widely-spread foundation slabs were used, and on one side of the river large stones were well rammed into the river bed and all voids grouted up to form a satisfactory foundation. The contractors were Messrs. J. W. G. Cronk, Ltd.

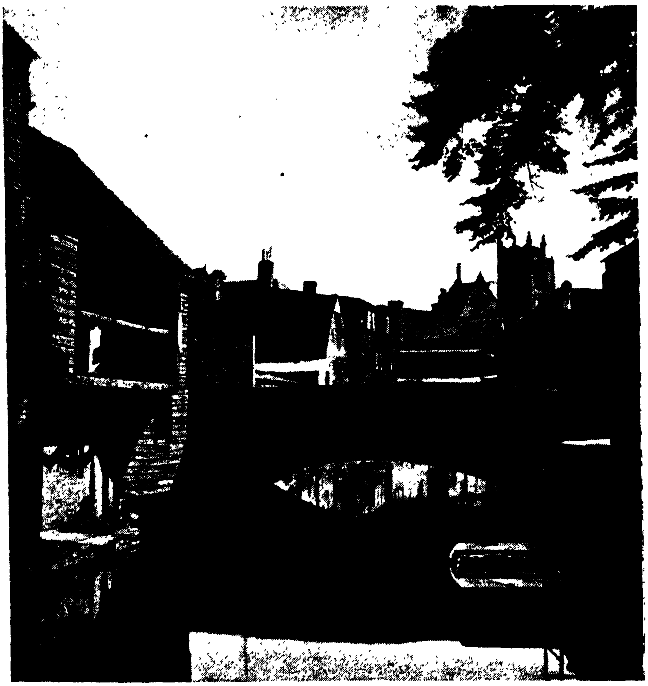
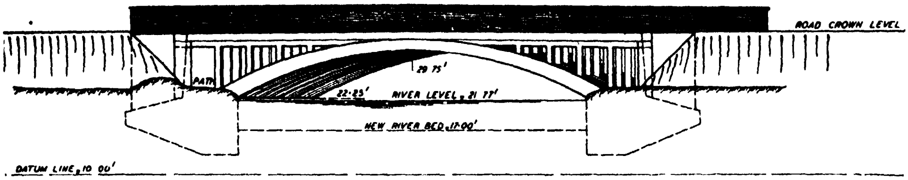


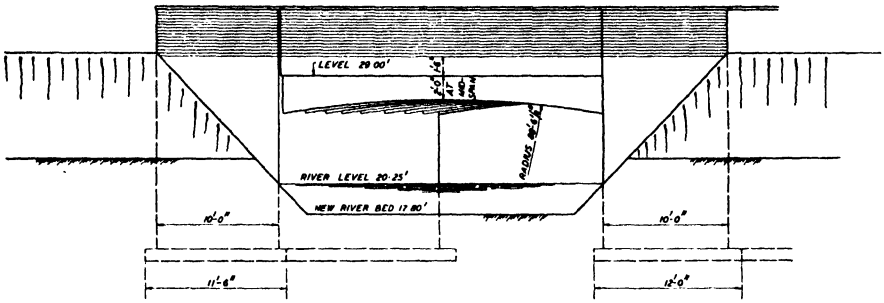
FIG. 70.—FRIARS BRIDGE, CANTERBURY.

Link Road Bridges.

The new link road from Northgate to St. Stephen's, Canterbury, crosses the main stream and back stream of the river Stour, and at both positions reinforced concrete bridges have been constructed. Both bridges (*Fig.* 71) are constructed on a skew, the spans being 57 ft. 6 in. and 26 ft. 6 in. The bridge over the main stream is of ribbed arch construction with mass concrete abutments, while the bridge over the back stream is a rigid-frame design. In both cases the parapets are con-



BRIDGE OVER MAIN STREAM.



BRIDGE OVER BACK STREAM

FIG. 71.—BRIDGES OVER THE RIVER STOUR, CANTERBURY.

structed in brickwork. Each bridge accommodates two 20-ft. carriageways with a 5-ft. dividing strip, and two 7-ft. 6-in. footpaths. As shown in *Fig.* 72, the arch bridge was constructed in halves and the formwork, after being used on the first half, was re-erected to construct the second half. The contractors were Messrs. J. W. Ellingham, Ltd.

These bridges were constructed under the direction of Mr. H. M. Enderby, M.Inst.M. & Cy.E., Engineer and Surveyor of the City of Canterbury. The British Reinforced Concrete Engineering Co., Ltd., acted as consulting engineers and supplied the designs and detail working drawings.

FIG. 72.—BRIDGE OVER MAIN STREAM, RIVER STOUR.

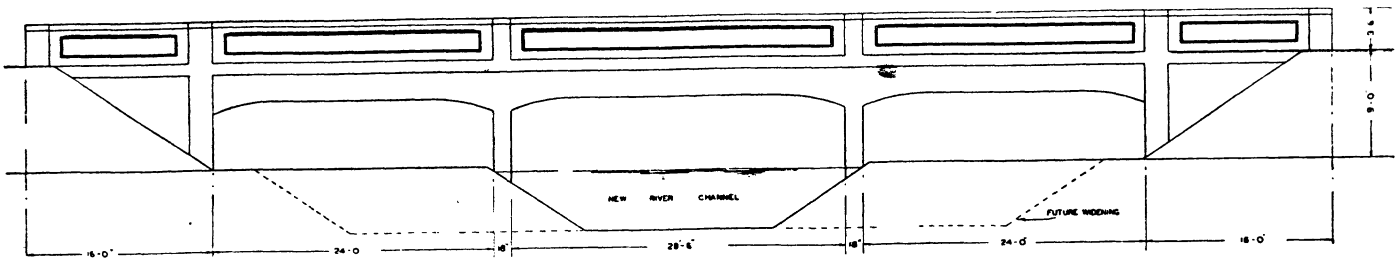


FIG. 73.—BRIDGE OVER THE RIVER SOWE.

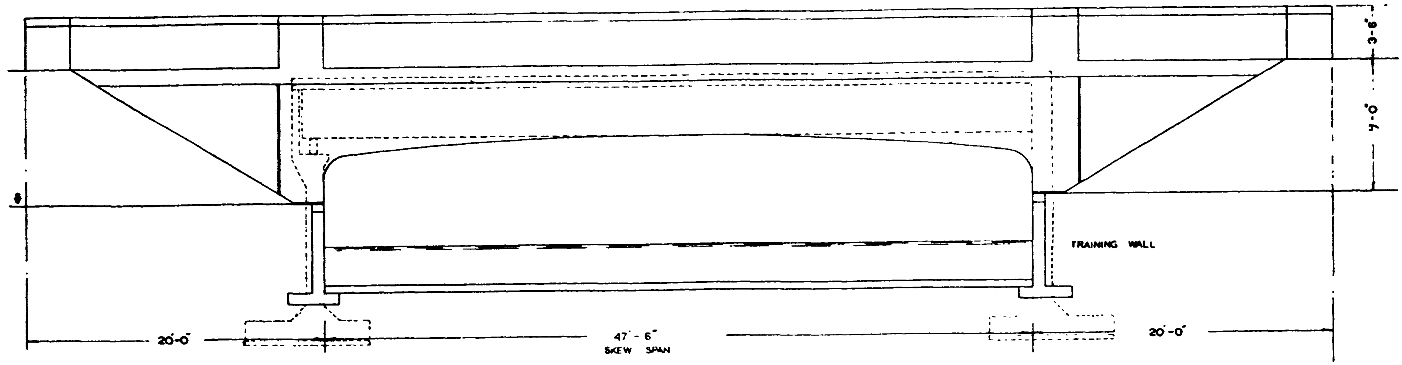


FIG. 74.—BRIDGE OVER THE RIVER SHERBOURNE.

THESE bridges will carry the Coventry by-pass road over the rivers Sowe and Sherbourne. Each bridge is 110 ft. wide between parapets, and will have dual carriageways 24 ft. wide with 8-ft. cycle tracks and footpaths. Along the centre there will be a grass strip 18 ft. wide.

The bridge over the river Sowe (*Fig.* 73) will be founded on Vibro piles, and will have two 24-ft. end spans and a 28-ft. 6-in. middle span. The decking will be a continuous reinforced concrete slab 1 ft. 7½ in. thick. The piers are of the open type with 18-in. by 15-in. columns spaced 7 ft. 10 in. apart to which the loads will be transmitted by top sill beams. The parapets will be in white concrete with panels recessed 2 in. At each pilaster there will be an expansion joint above the piers, and the coping will consist of double bull-nose pre-cast white concrete blocks.

The bridge over the Sherbourne (*Fig.* 74) is a single skew span of 47 ft. 6 in. crossing at an angle of 42 deg. 30 min. It has a beam-and-slab deck with an 8-in. slab and ribs at 6-ft. 9-in. centres under the road. The beams are 1 ft. 6 in. wide by 3 ft. 10 in. deep. The abutments are of the cantilever type, and training walls will be built along the river banks. The parapet will be similar to that on the river Sowe bridge.

These bridges were designed by Mr. E. H. Ford, M.Inst.C.E., City Engineer of Coventry, and are being built under his supervision.

MUDFORD BRIDGE, SOMERSET

Arches on Piled Foundations.

THE present Mudford Bridge over the river Yeo on the Frome–Yeovil road is only 14 ft. wide between the parapets, and is to be replaced shortly by two reinforced concrete arches of 28 ft. span each and 45 ft. between the parapets so as to relieve the obstruction to traffic on the A359 road. The new bridge (*Fig.* 75) has been designed by the County Surveyor of Somerset, Lt.-Col. Edward Stead, M.C., A.M.Inst.C.E., and will be built by contract.

Each arch vault will have a clear span of 28 ft. and a rise of 5 ft. to the soffit at the crown. The thicknesses will be 10 in. at the crown and 15 in. at the springings and the longitudinal reinforcement will consist of $\frac{3}{4}$-in. bars in the top and bottom at 6-in. centres in the middle portion between the splices and $\frac{3}{4}$-in. bars at 3-in. centres in the top and bottom between the splices and the abutments. The splices are 22 ft. apart and symmetrical about the crown. The distribution bars will be $\frac{1}{2}$ in. in diameter spaced at 6-in. centres throughout and placed inside the layers of upper and lower longitudinal bars.

Mass concrete will be used in building the pier and abutments and these will be founded on 12-in. square reinforced concrete piles. The pier will be 48 ft. long by 13 ft. high by 4 ft. 9 in. thick and will have a base 58 ft. long by 9 ft. wide by 2 ft. 6 in. thick carried on 57 piles arranged in rows of three and 3 ft. apart in both directions. The abutments will be 14 ft. 1 in. high on the river face and 12 ft. 6 in. wide. For a distance of 3 ft. in from the river face the bottom of the abutment will be horizontal, and beyond this it will slope upwards through a height of 2 ft. 6 in. The closing lines of the polygonal section will be a vertical 1 ft. 6 in. long at the back of the abutment and a tangent drawn from the upper end of this line to the extrados of the arch at the springing. Three rows of 12-in. piles will support each abutment, the inner row being driven vertically and the two outer rows at an angle of 15 deg. with the vertical. Longitudinally the piles will be at 3-ft. centres.

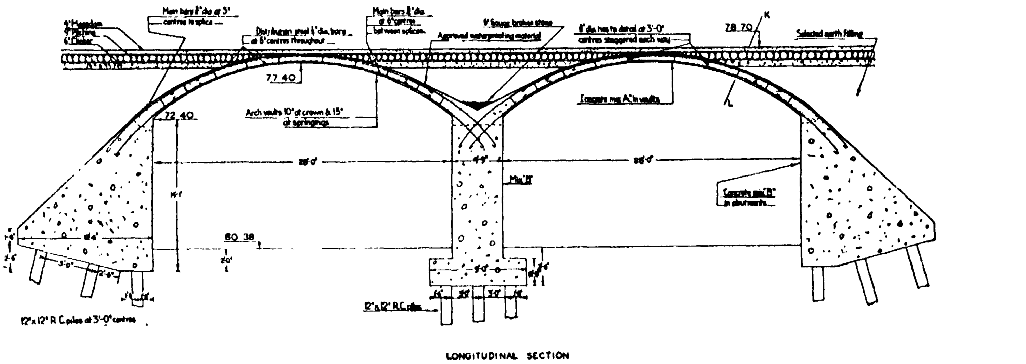


FIG. 75.—PROPOSED MUDFORD BRIDGE, SOMERSET.

Between the parapets, which will be 45 ft. apart, there will be two 11-ft. 6-in. paths and a 22-ft. carriageway with a 4-in. macadam surface on 9 in. of pitching laid above 6 in. of clinker. At the crown of the arch the road surface will be 1 ft. 4 in. above the soffit of the vault. Reconstructed Ham Hill stone will be used for the coping, cutwater cap, and voussoirs. The concrete will be mixed in the following proportions: Arch vaults, 4 : 2 : $1\frac{1}{4}$; abutments, pier, and wall foundations, 4 : 2 : 1; piles, 4 : 2 : $1\frac{3}{4}$.

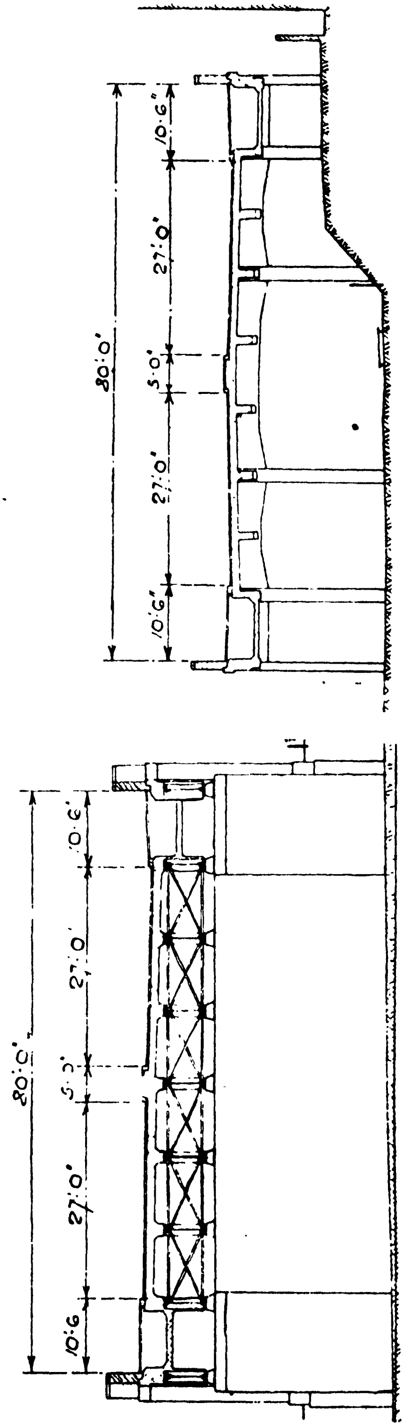
VIADUCT IN WEST LONDON

Continuous Open-trestle Spans.

THE extension of Cromwell Road to form a western exit from London, which was recommended in 1926 by the Royal Commission on Cross-River Traffic in London, will shortly be commenced by the London County Council. The first section will include a long viaduct and other work in reinforced concrete. Ultimately the extension will join Cromwell Road to the Chertsey by-pass road, which crosses the Thames on Chiswick Bridge, and to the circus where the Great West Road and the North Circular Road now meet near Kew Bridge. The new works have been designed by the Council's engineering staff under the direction of Mr. T. Peirson Frank, M.Inst.C.E., F.S.I., the Chief Engineer.

The length of the works, first stage including the approaches, will be about 1700 ft. extending from Warwick Road to North End Road. Starting at the east end an embankment will lead to the bridge over the West London Extension Railway and the London Passenger Transport Board railway. This bridge will have two clear spans of 76 ft. each, crossing eleven running lines in all, and the width between its parapets will be 80 ft. on which there will be two 10-ft. 6-in. paths, two 27-ft. carriageways to take six lines of traffic and a central strip 5 ft. wide to divide the carriageways. The superstructure has been designed with steel-plate girders and a reinforced concrete deck, and will be carried on reinforced concrete abutments and a mass concrete pier faced with brickwork at its ends. The abutment at the east end will be a counterforted wall, but at the west end the cellular type will be used. Reinforced concrete will also be used in constructing the wing walls.

To the west of this bridge there will be a 27-ft. 6-in. span over two sidings on the London Passenger Transport Board's railway, and beyond this a reinforced concrete viaduct designed, for the most part, with open trestles and 18-ft. spans and divided at intervals of 56 ft. 7 in. by duplicate columns to allow for movements due to rise and fall of temperature. From the end of this viaduct there will be an embankment between mass concrete retaining walls.



CROSS SECTION THROUGH APPROACH VIADUCT.

CROSS SECTION THROUGH MAIN SPAN.

FIG. 76.

CLEOBURY MORTIMER BRIDGE, SHROPSHIRE

Widening on Two Sides.

THE old Cleobury Mortimer bridge, which carried the Cleobury Mortimer to Bewdley road (A4117) over the river Rea, was a masonry arch bridge of 40 ft. span and 16 ft. 6 in. wide between parapets. The bridge, which was in a good state of repair, has been strengthened and widened on both sides to a width of 40 ft. between parapets. For the strengthening of the existing bridge a reinforced concrete saddle was provided and the size of the abutment increased.

The widened portion of the bridge is a reinforced concrete arch vault on mass concrete foundations carried down to the natural rock. The arch vault is 1 ft. 3 in. thick at the crown and reinforced with ⅞-in. diameter bars at 7-in. centres top and bottom; the vault increases to 18 in. thick at the springing. The joints between the existing and widened portions of the bridge are plain butt joints, ties being provided between the two new portions.

There is a distance of 30 ft. between the level of the road and the bed of the stream, involving high wing walls to retain the approach embankment. These wing walls are curved in plan and consist of reinforced concrete counterfort walls supported on mass concrete foundations.

The centering for the underside of the arch vault was lined with hessian, which has afforded a pleasing finish and eliminated board marks. The wing and spandrel walls are faced with local stone, while the stringcourse and coping are of concrete cast in situ.

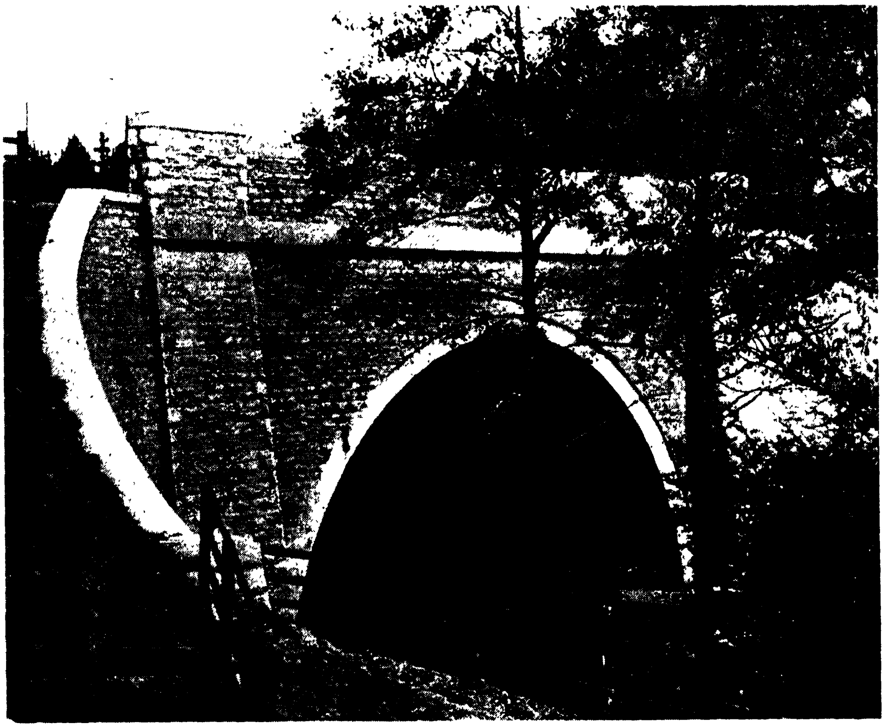


FIG. 77.—CLEOBURY MORTIMER BRIDGE WIDENING.

The bridge work (*Fig.* 77) was designed and executed by direct administration under the direction of the County Surveyor, Mr. William H. Butler, M.Inst.C.E. The total cost of the scheme, including the cost of the land, amounted to £7,306, of which the bridge works accounted for £2,406.

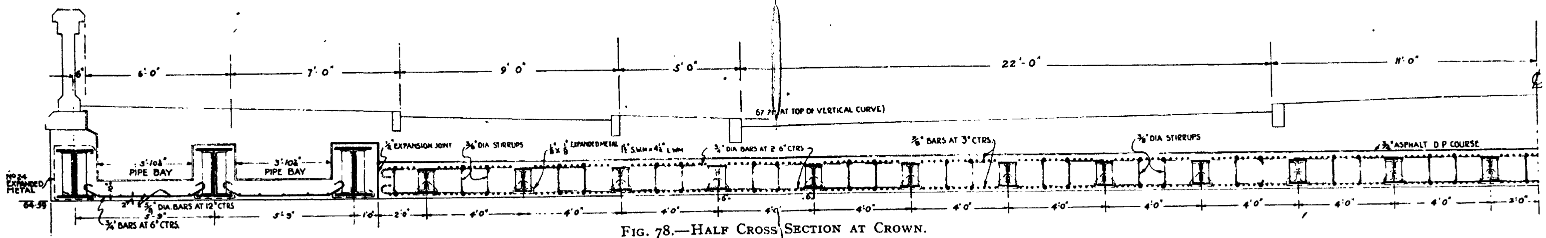


FIG. 78.—HALF CROSS SECTION AT CROWN.

DUNNINGS CANAL BRIDGE, LANCASHIRE

Width of 120 ft.

THE latest bridge to be constructed over the Leeds and Liverpool Canal carries the new 120-ft. by-pass road, known as the Dunnings Bridge–Litherland Road. The conditions laid down by the canal company required a 40-ft. square span and 11-ft. clearance.

Although the site was free from development and did not rule out ordinary plate girder construction, in view of the road width it was decided to reduce the constructional depth to a reasonable minimum, and with this object a portal frame was decided on. In a road of this width, using the same approach gradients and vertical curves, a reduction of 1 ft. in constructional depth effects a saving of about 7,200 cu. yd. of filling.

Details of the Design.

The bridge (*Fig.* 79) is a composite one; the main barrel is a reinforced concrete portal, 1 ft. 6 in. thick at the crown and 3 ft. 11 in. at the corners, with legs averaging 2 ft. 6 in. (see *Fig.* 81, p. 78). On each side of the main barrel are two pipe bays carried between plate girders at 5-ft. 9-in. centres; these are 2 ft. over the angles at the crown and 4 ft. at the abutments, the cambered bottom flanges following the line of the portal soffit. The extra depth available for the pipe-bay girders is due to the road section, cross falls, and kerb levels allowing a greater depth under the footpath and verges. The pipe-bay girders are carried on mass concrete abutments, the two types of construction being separated by bituminous sheeting protected by a copper strip of the expansion joint type. To simplify the construction of the portal and to avoid obstructing the canal, steel frames, designed to carry the dead load of concrete and shuttering, were incorporated in the structure at 4-ft. centres; these supported the lagging during the process of placing the concrete. A cross section of half the width of the bridge is shown in *Fig.* 78.

FIG. 79.—DUNNINGS CANAL BRIDGE.

Construction.

The distribution steel was carried through below the bottom flanges of the frames, which were surrounded with expanded metal, in order to reduce the tendency for the cover concrete to crack. The pipe-bay girders were concreted in full depth, the bottom flanges being similarly covered with expanded metal. The elevation of the bridge is treated as if the portal extended through to the face. The abutment quoins and projecting arrises and margins are chisel drafted and the remaining face-work hand dressed to expose the aggregate. Experiments made during the progress of the work showed that a more uniform and pleasing appearance is obtained in the margins if these are ruled when "green" with a special steel comb, and this method was adopted in the later stages when the cast-in-situ work above the stringcourse was being undertaken. The parapet is built up in pre-cast units between cast-in-situ pilasters (*Fig.* 80).

The ease with which this bridge was constructed serves to emphasize the hindrances in cases of reconstruction which may involve forming temporary horse ramps, constructing the bridge-works piecemeal, demolition in two or more stages, forming temporary roads, supporting and diverting services, etc., which, added together, appreciably affect progress and smooth working.

The bridge was designed by Mr. P. Schofield, County Surveyor of Lancashire, and the contractors were Messrs. Bolton and Lakin, Ltd. The reconstructed stonework is by the Naybro Stone Co., Ltd.

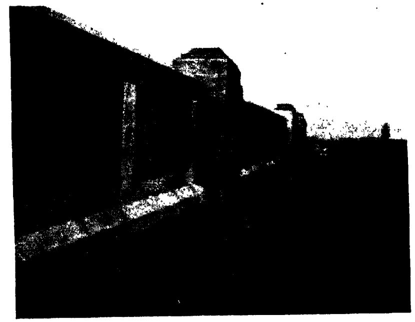


FIG. 80.—SHOWING TREATMENT OF PARAPET.

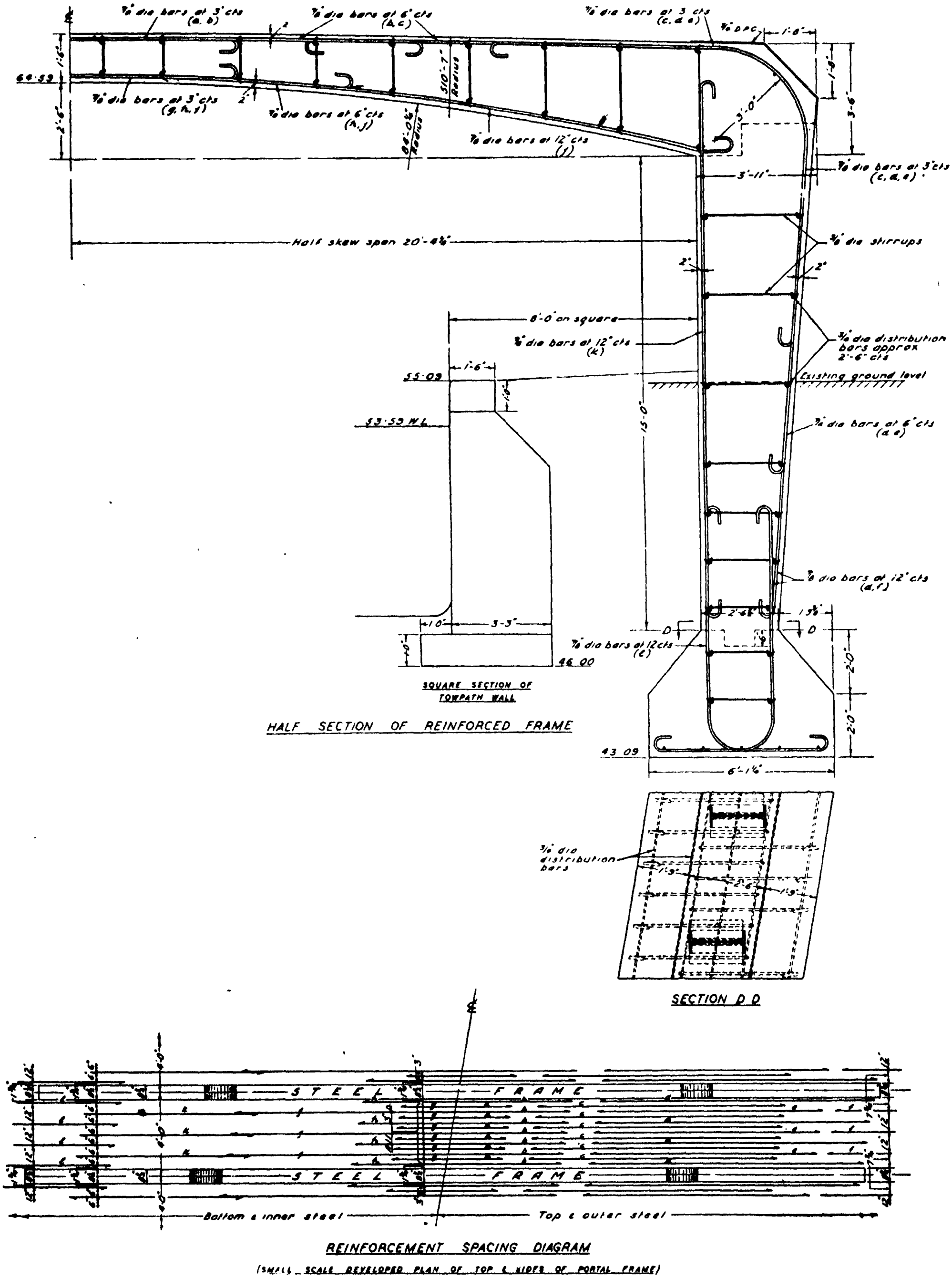


FIG. 81.—DUNNINGS CANAL BRIDGE, LANCASHIRE.

RUSHBED BRIDGE, LANCASHIRE

Stream Culverted over 500 ft.

RUSHBED (COUNTY) BRIDGE carries the Class I county road A56 from Manchester to Burnley over the river Limy Water in the Borough of Rawtenstall. As the river runs parallel to the road for a considerable distance immediately south of the existing bridge, it was necessary when a road widening scheme was proposed to culvert the stream the full distance of the widening (*Fig.* 82). This was done in accordance with plans prepared by the County Surveyor of Lancashire, Mr. P. Schofield.

Twin culverts 10 ft. by 5 ft. in section give the necessary water area, 5 ft. being the available headroom at the southerly end and a total width of 22 ft. 9 in. the greatest which could be built through the existing arch bridge without demolishing it. The culverts were therefore constructed completely without interference from road traffic. The design is in the form of a box culvert with a flexible joint at the junction of the central wall and roof slab (*Fig.* 83). A dead load of 16 ft. of filling was allowed for, this being the depth below road level at the northerly end. As the depth of filling reduces towards the southerly end, the live load effect increases, and the culvert design was checked for the full Ministry of Transport loading with 2-ft. dead load, which is the condition found at the southerly end.

Construction.

A 6-in. bed of concrete was first laid and a dam was erected on this. The culverts were then built in 120-ft. lengths, the water being controlled through alternate sections. The invert, side walls, and central wall were completed before the roof slab was erected. Erection of the roof slab was carried out in a north to south direction, and was followed by the filling and demolition of the existing bridge.

The culverts are protected by a ¾-in. asphalt covering and drained on each side with dry stone backing and 6-in. pipes. Internally, the invert and walls for a height of 2 ft. 6 in. are protected by a waterproof cement rendering. The contractors were Messrs. Drake Bros. (Haslingden), Ltd.

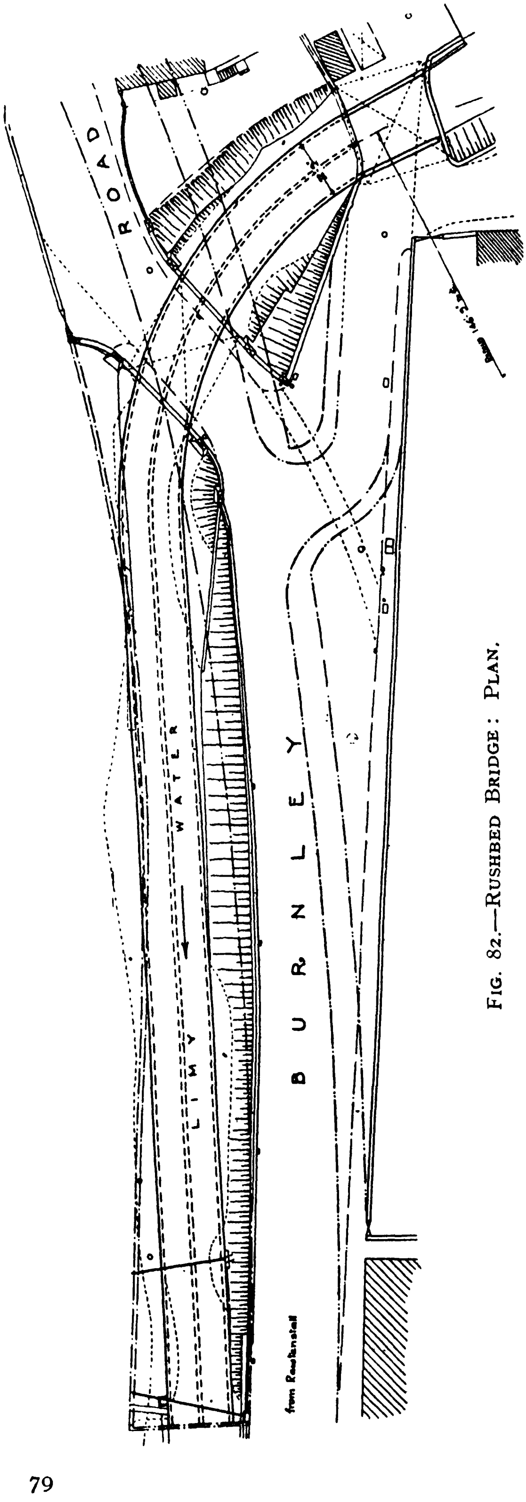
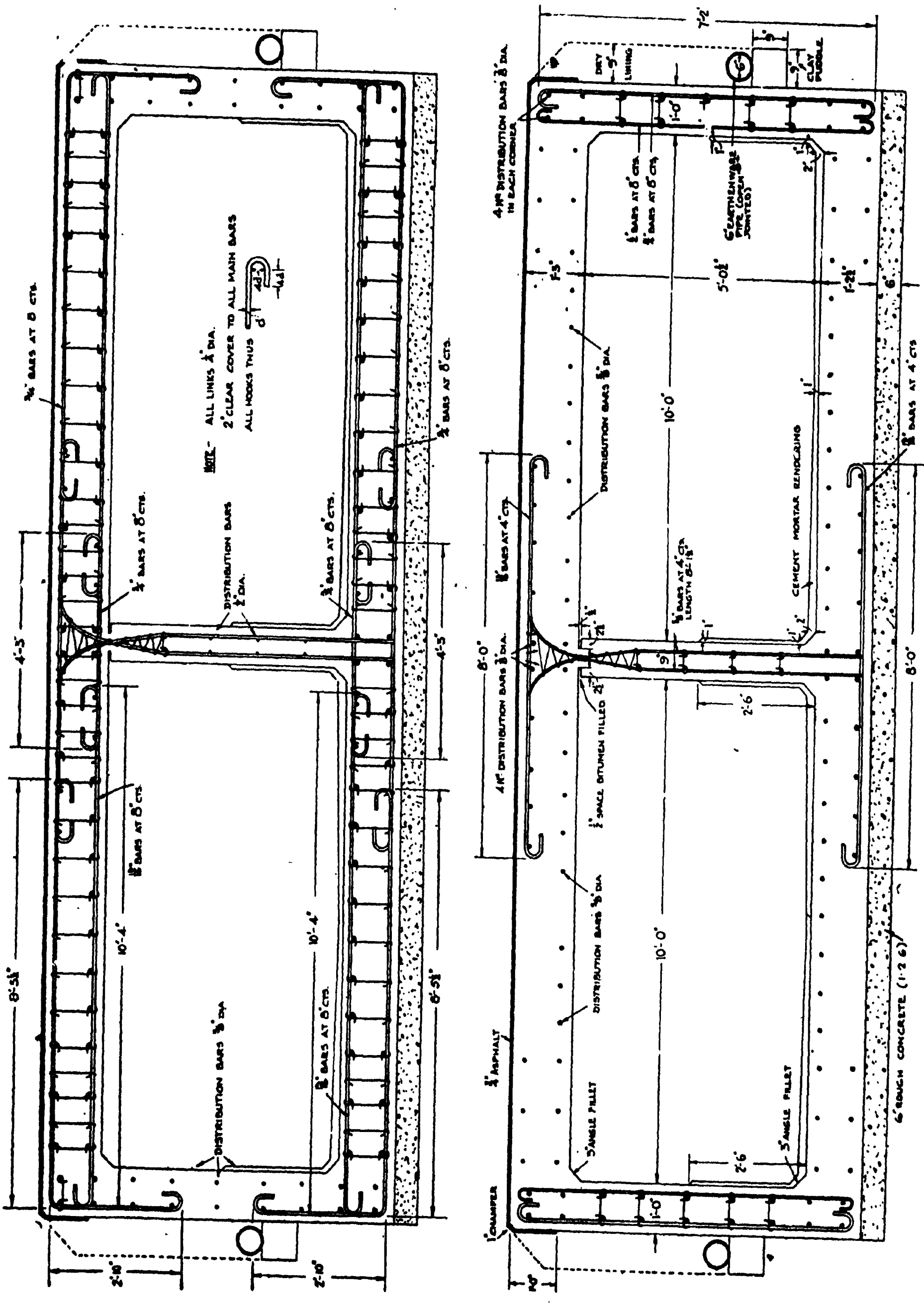


FIG. 82.—RUSHBED BRIDGE: PLAN.



SECTIONS OF CULVERT AT ALTERNATE 4-IN. CENTRES.

FIG. 83.—RUSHBED BRIDGE, LANCASHIRE

THE four bridges described have been carried out to the design and under the supervision of Mr. Wm. A. Chapman, County Surveyor of Lanarkshire.

Telford Bridge.

Telford Bridge (*Fig.* 84) is a trunk road bridge on the Glasgow–Carlisle road (A74) and crosses over the river Clyde near Elvanfoot. The bridge is a reinforced concrete arch vault, 96 ft. skew span, earth filled and supported on mass concrete abutments. The width of the bridge between parapets is 60 ft., which accommodates 22-ft. dual carriageways, a 6-ft. central verge and two 5-ft. wide footpaths.

The north abutment was founded on 102 18-in. diameter and twenty 14-in. diameter Prestcore piles bored through bound gravel to the rock stratum; the south abutment was founded directly on the rock stratum. The abutments, pilasters and spandrel walls were faced with red freestone masonry. The contractors were Messrs. Murdoch Mackenzie, Ltd.

Craig Bridge.

Craig Bridge (*Fig.* 85), on the Strathaven–Lesmahagow road (A726) approximately one mile south-east of Strathaven, was constructed by Messrs. Hugh Leggat, Ltd. The bridge carries a highway diversion over the river Avon and has a span of 90 ft. and a width between parapets of 50 ft. It consists of a segmental reinforced concrete arch vault with filled spandrels and mass concrete abutments. The abutments, spandrels, and wing walls are faced with white freestone masonry, and white freestone ashlar masonry was used to form the parapets.

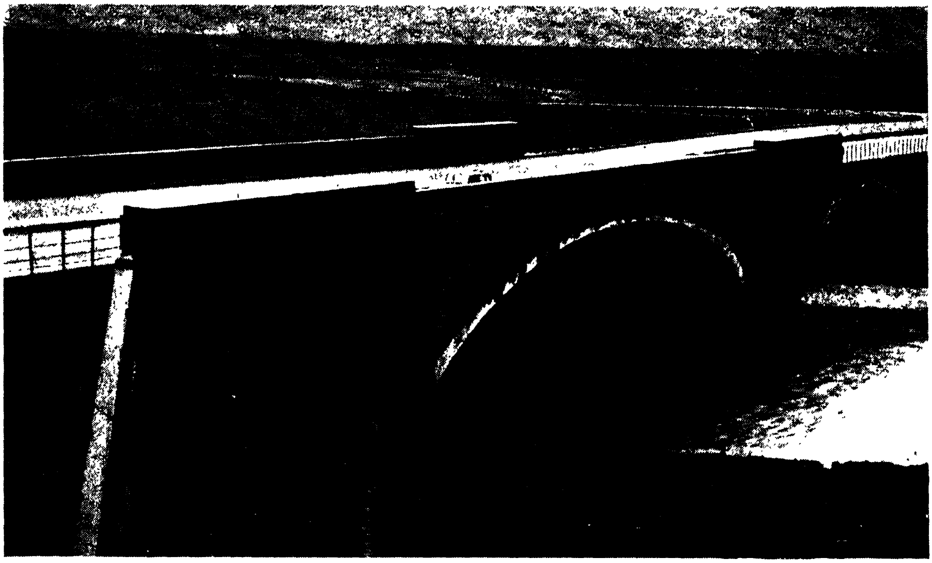


FIG. 84.—TELFORD BRIDGE.

Cowford Bridge.

About half a mile north-west of Carstairs on the Carluke–Peebles highway (A721), Cowford Bridge (*Fig.* 86) carries a road diversion over the Mouse Water. It has a skew span of 70 ft. $8\frac{1}{2}$ in. and a square span of 50 ft. (angle of skew 45 deg.). The width between parapets is 40 ft. It consists of a segmental reinforced concrete arch vault with filled spandrels and mass concrete abutments. The abut-

FIG. 85.—CRAIG BRIDGE.

ments, spandrels and wing walls are faced with whinstone masonry, while the quoins, the voussoirs of the arch rings, and the parapet wall cope are of white freestone masonry. The contractors were Messrs. James White (Contractors), Ltd.

Busby Bridge.

This bridge, in course of construction, is situated in Busby and will carry the Busby highway (route A726) over the White Cart Water. It is a joint bridge with the County of Renfrew.

The bridge is a segmental reinforced concrete arch vault of 60 ft. span, earth filled, and supported on mass concrete abutments founded directly on rock. The width between parapets is 50 ft., accommodating a 30-ft. carriageway and two 10-ft. footpaths. The abutments and spandrels and wing walls are faced with white freestone masonry, and the parapets are of ashlar masonry.

Figs. 87 and 88 show the falsework erected to carry the shuttering and a view of one-half of the completed bridge. The contractors are Messrs. Murdoch Mackenzie, Ltd.

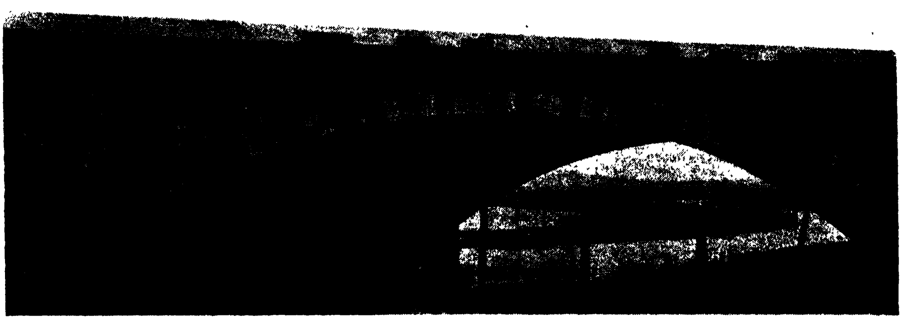


FIG. 86.—COWFORD BRIDGE.

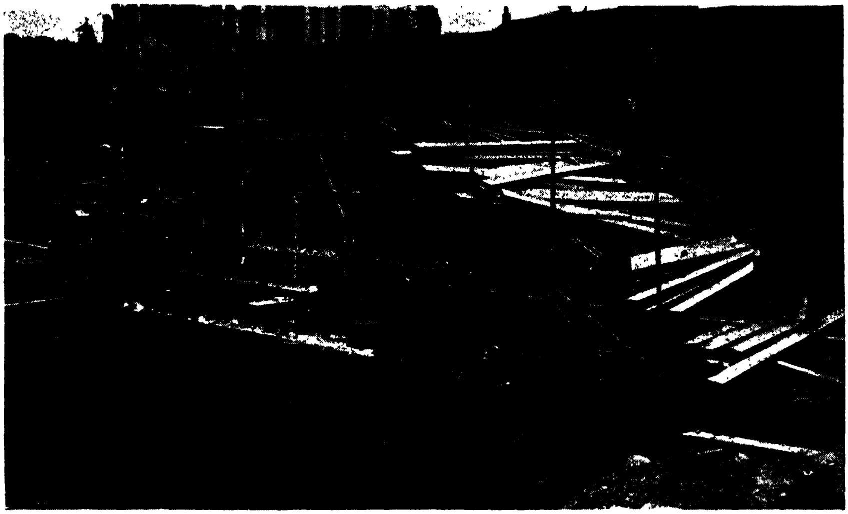


FIG. 87.—BUSBY BEIDGE: SHOWING CENTERING USED FOR REMOVAL OF ARCH OF OLD BRIDGE.

FIG. 88.—BUSBY BRIDGE: VIEW OF COMPLETED HALF OF BRIDGE.

BRIDGE OVER THE RIVER CART, GLASGOW

An elevation of the reinforced concrete bridge to be erected over the river Cart, at Pollok, in accordance with the design prepared by the staff of Mr. Thomas Somers, C.B.E., M.Inst.C.E., City Engineer, Glasgow, is shown in *Fig.* 90.

The clear span of the bridge is 70 ft. and the superstructure is of tee-beam and slab design with the beams supported on cast-steel rocker bearings. The width of the bridge will be 80 ft. between the parapets, and the roadway will incorporate dual carriageways in accordance with the Ministry of Transport's regulations. Expansion joints will be carried across the roadway and through the parapets, which are to be of grey granite. The abutments and wing walls will be of counterfort design.

In all there are six tee beams, two L beams, and two simple beams—each 75 ft. long—six under the road and one under each kerb and parapet. Between the centre lines of the kerb and parapet beams on each side the distance is 12 ft. 5 in.; all other beams are spaced at 8-ft. transverse centres (*Fig.* 89). The road beams (*Figs.* 91 and 92) are 5 ft. 9 in. deep overall, with an 8-in. slab, and are 2 ft. 4 in. wide. At the middle of their spans there are three $1\frac{1}{4}$-in. bars in the top and fifteen $1\frac{7}{8}$-in. bars in three layers in the bottom. No bars are bent up, the whole shear being taken by $\frac{1}{2}$-in. stirrups with four prongs on each. Under the kerbs the beams are 2 ft. 10 in. wide by 5 ft. 5 in. deep, and under the parapets 18 in. wide at the narrowest part by 6 ft. 6 in. deep. Between the kerb and parapet beams there are 8-in. slabs forming the floors of the pipe ducts.

The general detail of the abutments provides for counterfort construction with a base slab 20 ft. wide 28 ft. below the concrete level at the bridge bearing. The vertical slab will be 9 in. thick and 6 ft. back from the toe of the wall, and the counterforts will be at 8-ft. centres and 2 ft. 6 in. thick.

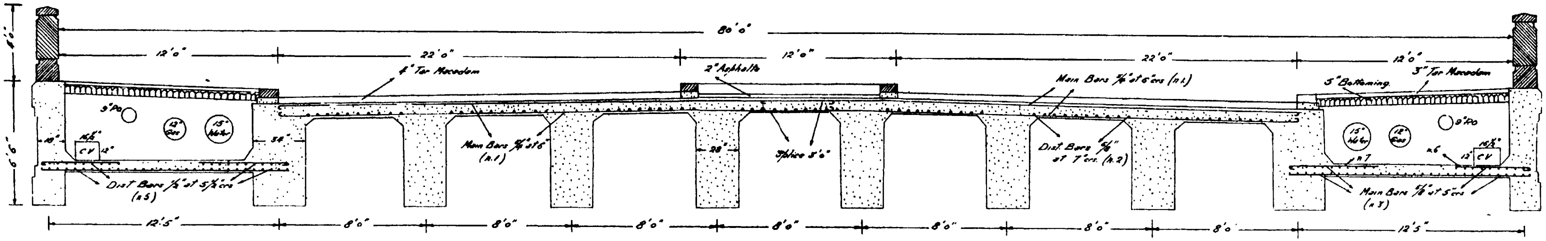


Fig. 89.—Cross Section.

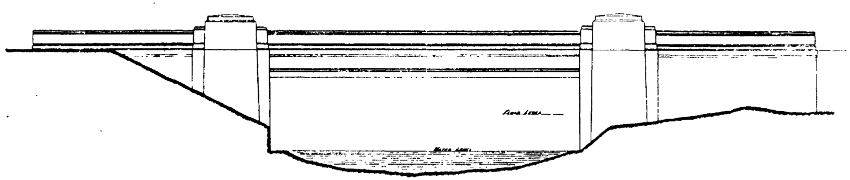


Fig. 90.—Elevation.

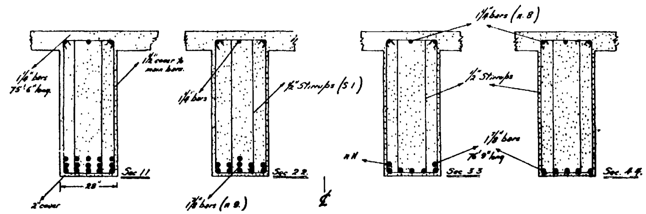


Fig. 92.—Cross Sections of Roadway Beams.

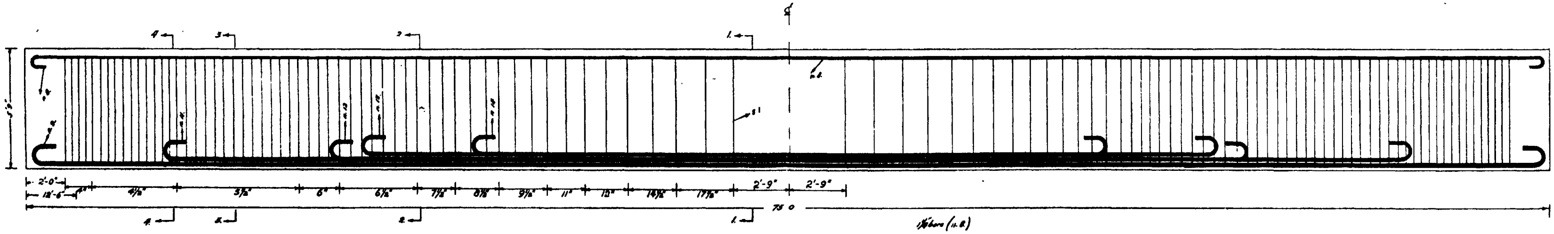


Fig. 91.—Roadway Beams.

NEW BRIDGES IN THE ISLE OF ELY

Cost 15s. per square foot of Deck.

THREE reinforced concrete bridges are now in course of construction in the Isle of Ely, one on the Whittlesey-Doddington road (B1093) at Benwick over the old course of the river Nene, and two at Sutton Gault carrying an unclassified road over the Hundred Foot river (New Bedford river) and the Old Bedford river. The designs and details for all three schemes have been prepared by the staff of the County Surveyor, Mr. A. Morwood, A.M.Inst.C.E., F.S.I., the bridge structures being carried out by contract and the road and approach works by direct labour. The three existing bridges were all owned by drainage authorities, and are being taken over and reconstructed by the Isle of Ely County Council with the aid of 75 per cent. grants from the Ministry of Transport.

45-ft. Span Slab Bridge at Benwick.

The bridge at Benwick will replace a timber structure built in 1862, and which for some years past has been subject to a weight restriction. The new bridge is about 170 yd. north-east of the present bridge adjacent to the railway sidings, and 200 yd. of new road will be constructed to link up with the road to Doddington and improve the alignment.

The Middle Level Drainage Commissioners, who are the navigation and drainage authority for the river Nene (Old Course), allowed the soffit level of the new bridge to be 18 in. lower than the present bridge but required a clear span for the river with no permanent obstructions. In these slowly-moving drains obstructions usually encourage rapidly growing weeds with attached debris which soon reduce the waterway for drainage purposes. Consequently a centre span of 45 ft. was required. In order not to affect the entrance to the railway sidings and to give easy grades and adequate visibility, it was essential to keep the depth of construction of the bridge as small as possible. By using a rich concrete (150 lb. : 2 cu. ft. : 4 cu. ft.) with a design stress of 1,050 lb. per square inch the depth at the middle of the centre span was kept down to an average of 24 in. Borings showed good hard-cutting clay at a depth of 40 ft. overlaid by a 14-ft. bed of gravel. Above these came strata of peat, soft clay, and silt, which are typical of the Fen districts. In order to reduce excavation costs and to keep the overall length of the bridge as small as possible consistent with a central span of 45 ft., a continuous centre span with end cantilevers of 16 ft. on pile supports was decided on. Slab construction was considered to be more economical for these spans.

Details of the bridge are shown in *Fig.* 93. The centre-span slab average thickness of 24 in. is increased to 36 in. over the supports by 10-ft. haunches, while the deck is cambered to fit the roadway and a uniform surfacing 2 in. in thickness will be laid over the concrete. Twenty-two 14-in. by 14-in. reinforced concrete piles, each carrying a load of 40 tons and capped by a beam 2 ft. 6 in. wide, support the bridge. These supports are monolithic with the deck and joined by 1-in. dowel bars at 12-in. centres. The effective width between parapets is 32 ft., providing a 20-ft. carriageway and two 6-ft. paths; provision is made for all mains and cables in the ducts under the footpaths which are covered with pre-cast slabs for easy access.

With this type of structure it is essential that the ends of the cantilevers should not receive support so as to transfer moment to the middle of the central span. A short 6-in. concrete curtain wall has been formed at the end of the slab to retain the filling, and when constructed the material below the wall is not consolidated so that any necessary movement shall not be restricted. Approach slabs are provided at the ends of the bridge resting on ledges formed in the ends of the cantilevers; these slabs will be free to move as the approaches settle and will prevent the formation of steps at the ends of the bridge.

The main reinforcement in the deck slab consists of 2-in. bars at 8-in. centres in the bottom of the middle span, with 2-in. bars at 10-in. centres in the top and throughout the cantilever and lapped 7 ft. at the centre. With the end spans fully loaded and dead load only on the central span there is negative moment throughout the spans, necessitating reinforcement

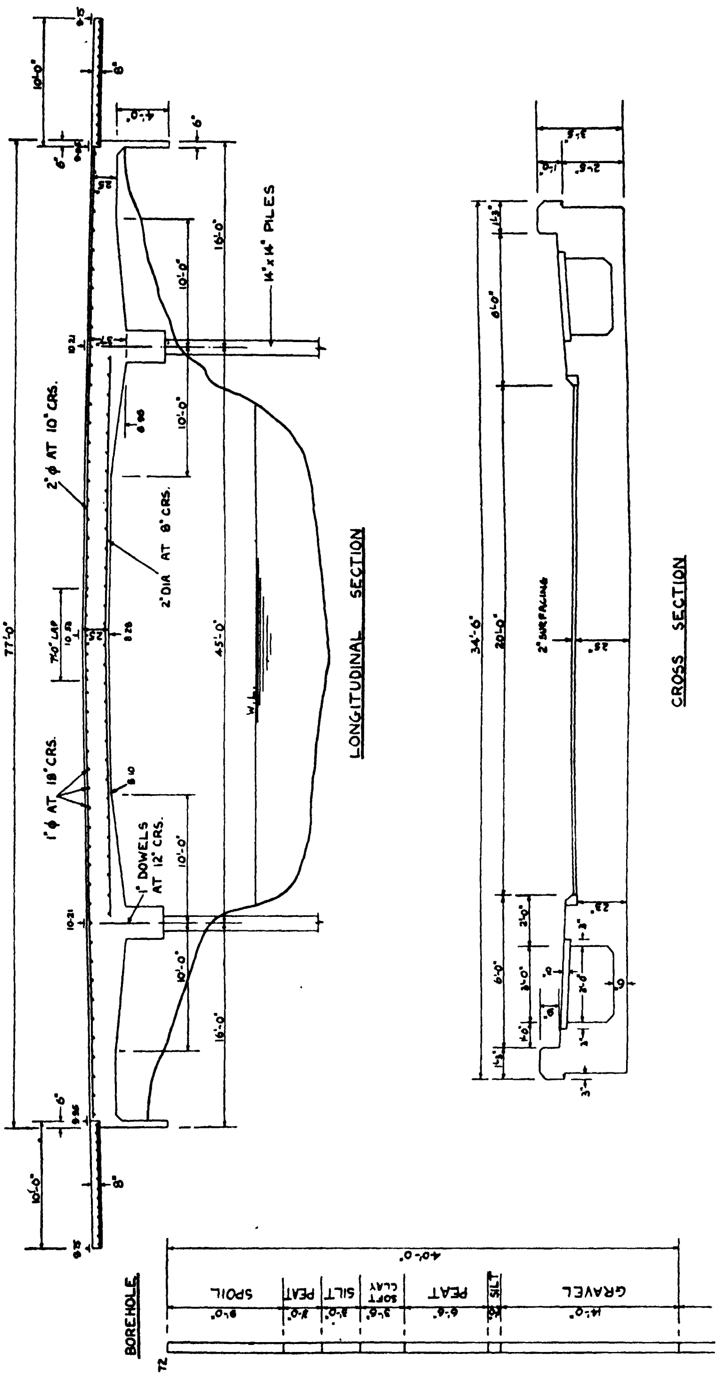

LONGITUDINAL SECTION
77'-0"
45'-0"
16'-0"
10'-0"
10'-0"
4'-0"
2"φ AT 10" CRS.
2" DIA AT 8" CRS.
1"φ AT 18" CRS.
1" DOWELS AT 12" CRS.
7'-0" LAP
14"x14" PILES
W.L.
CROSS SECTION
34'-6"
20'-0"
6'-0"
2" SURFACING
BOREHOLE
40'-0"
SPOIL
PEAT
SILT
SOFT CLAY
PEAT
SILT
GRAVEL

FIG. 93.

in the top at the middle of the central span also. This steel is used as compression steel when calculating the reinforcement required for the midspan under maximum positive moment. This allows a small saving in the construction depth at the centre.

Design Calculations.

Brief details of the main calculations for the bridge are as follows:

DATA.—$f_c = 1{,}050$ lb. per square inch; $R = \frac{M}{bd^2} = 197$; $m = 12$; $j = 0{\cdot}86$; $f_s = 16{,}000$ lb. per square inch; Ministry of Transport Standard Loading.
Slab thickness neglecting haunches = 24 in. average.

Dead Load:

Slab	$24 \times 12 =$	288
Surfacing	$2 \times 10 =$	20
		308 lb. per sq. ft.
Live Load:		220 lb. per sq. ft.

MAXIMUM POSITIVE MOMENT IN CENTRAL SPAN.—

Free moment, fully loaded:

		(lb.-ft.)
Uniform load	$528 \times \frac{45^2}{8}$	$= 134{,}000$
Point load	$2{,}700 \times \frac{45}{4}$	$= 24{,}000$
Haunches	$2 \times 1{,}200$	$= 2{,}400$
		160,400

Minimum cantilever moment neglecting approach slab:

		(lb.-ft.)
Uniform load	$308 \times \frac{16^2}{2}$	$= 39{,}400$
Haunch		$= 2{,}400$
Curtain wall	$4 \times \frac{1}{2} \times 144 \times 15{\cdot}75$	$= 4{,}500$
		46,300

∴ Maximum positive moment in central span = 114,100 lb.-ft.

$$R = \frac{114{,}100}{21^2} = 259.$$

Use compression steel.

$M_1 = 197 \times 21^2 = 87{,}000$ lb.-ft.

$$A_T = \frac{87{,}000 \times 12}{16{,}000 \times 0{\cdot}86 \times 21} = 3{\cdot}61 \text{ sq. in.}$$

$$\text{Extra } A_T = \frac{27{,}100 \times 12}{16{,}000 \times 18} = 1{\cdot}13 \text{ sq. in.}$$

∴ Total $A_T = 4{\cdot}74$ sq. in.
Use 2-in. bars at 8-in. centres = $4{\cdot}71$ sq. in.
Moment taken by compression steel = 27,100 lb.-ft.
Compression steel stress

$$= \frac{12 \times 1{,}050\ (0{\cdot}44 \times 21 - 3)}{0{\cdot}44 \times 21}$$

= 8,500 lb. per square inch.

$$\text{Required } A_C = \frac{1{\cdot}13 \times 16{,}000}{8{,}500} = 2{\cdot}13 \text{ sq. in.}$$

A_C provided = $3{\cdot}77$ sq. in. for negative moment (see later).

MAXIMUM CANTILEVER MOMENT.—

		(lb.-ft.)
Uniform load	$528 \times \frac{16^2}{2}$	$= 67{,}600$
Haunch		$= 2{,}400$
Curtain wall		$= 4{,}500$
Point load	$2{,}700 \times 16$	$= 43{,}200$
Approach slab	$4{\cdot}75 \times 336 \times 16$	$= 25{,}500$
		143,200

$A_T \doteq 3{\cdot}79$ sq. in. Use 2-in. bars at 10-in. centres = $3{\cdot}77$ sq. in.

MAXIMUM NEGATIVE MOMENT AT END OF HAUNCH.—

Free moment due to dead load only:

		(lb.-ft.)
Uniform load	$\frac{308 \times 10 \times 35}{2}$	$= 54{,}000$
Haunches		$= 2{,}400$
		56,400

∴ Maximum negative moment = 86,800 lb.-ft.

$A_T = 3{\cdot}60$ sq. in. Use 2-in. bars at 10-in. centres = $3{\cdot}77$ sq. in.

MAXIMUM NEGATIVE MOMENT IN CENTRAL SPAN.—

Free moment, dead load only:

		(lb.-ft.)
Uniform	$308 \times \frac{45^2}{8}$	$= 78{,}000$
Haunches		$= 2{,}400$
		80,400

∴ Maximum negative moment = 62,800 lb.-ft.

$A_T = 2{\cdot}61$ sq. in. Use 2-in. bars at 10-in. centres with reduced lap of 7 ft.

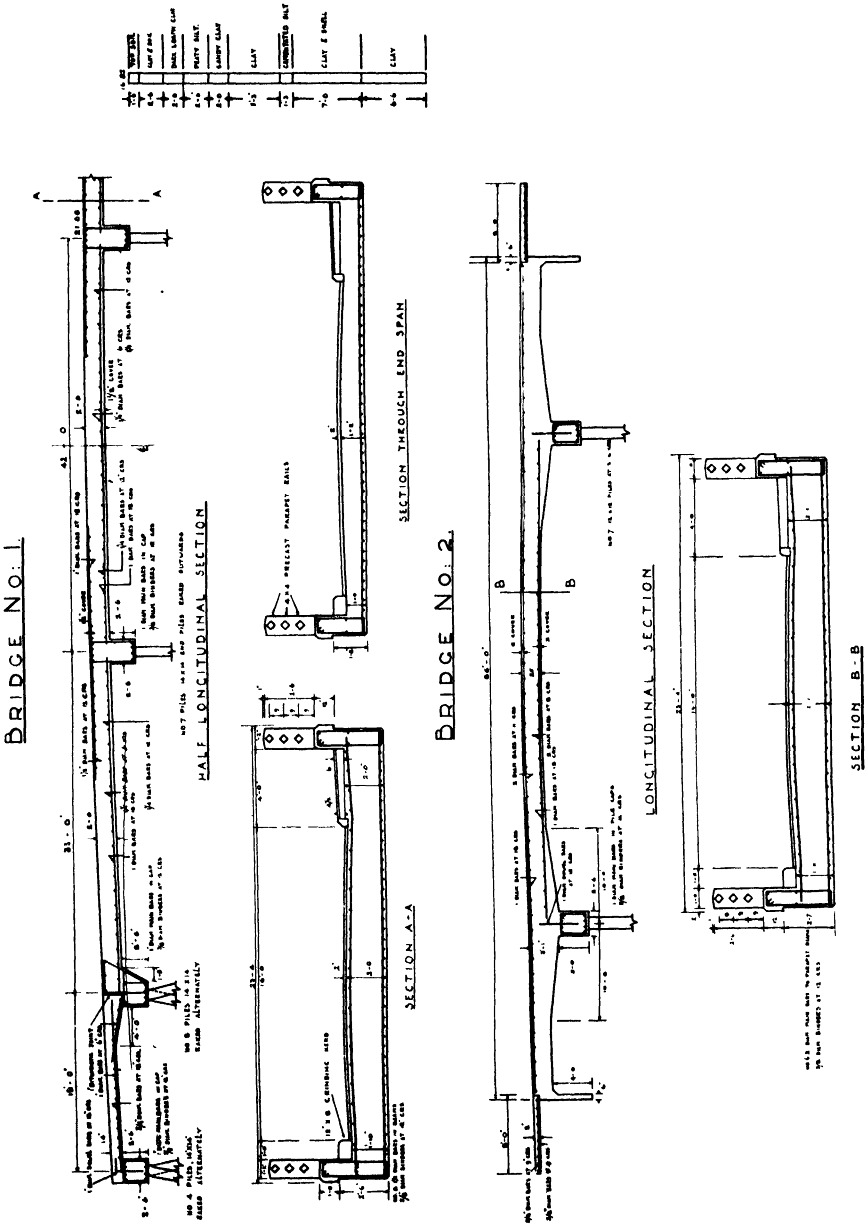

BRIDGE No: 1
HALF LONGITUDINAL SECTION
SECTION THROUGH END SPAN
SECTION A-A
BRIDGE No: 2
LONGITUDINAL SECTION
SECTION B-B

FIG. 94.

Economical Type of Bridge at Sutton Gault.

The two timber structures at Sutton Gault, the date of erection of which cannot be ascertained, are typical examples of the old Dutch bridges common in the Fen district. These bridges had a road width of 12 ft. only, with no footpaths and very sharp approaches. The timber beams and pile trestles were in exceptionally bad condition and in some cases the piles were completely rotted through at water level. The abutment piles to the bridge over the Old Bedford river sank about 3 ft. in the course of a week a few months ago, and it was necessary to replace the beams of the west end span of this bridge with long timbers taking their bearing on the river bank about 10 ft. behind the old abutment. This temporary measure proved very effective until the new bridge was recently opened to traffic.

Of about twenty bridges reconstructed during the last five years in the Isle of Ely, it is claimed that the design adopted for these two bridges has resulted in the most economical type of structure, since the unit cost of the bridge is only £0·76 per square foot of deck. Other bridges of various types have varied in cost from £2 to £1·15 per square foot of deck.

Owing to the very minor traffic value of the road the most important condition governing the design of the new bridges was to keep their cost as low as possible whilst complying with the requirements of the drainage authority (the River Great Ouse Catchment Board) with regard to headroom and waterway widths, allowing so far as possible for future widening and dredging.

The spans for the bridges were decided as shown in the longitudinal sections (*Fig.* 94), the end spans for bridge No. 1 and the cantilevers on bridge No. 2 being added to eliminate costly abutments and wing walls. Following negotiations with the Ministry of Transport it was agreed that a road width of 16 ft. together with a 4-ft. path and a 12-in. grinding kerb would be sufficient for traffic requirements.

A cheap and effective parapet has been provided for both bridges by using in-situ concrete posts at 6-ft. to 7-ft. centres with three 4-in. by 4-in. pre-cast concrete diamond-shape rails. The cost of the parapets, including the piers, averaged about 3*s.* 10*d.* per foot run.

Both bridges have been designed with a parabolic vertical curve and the approaches have a slope of 1 in 28 in order to lower the road to fen level as soon as possible. This was necessary as the "wash" land some 300 yd. in length between the two bridges (including the road itself) is inundated at certain times of the year to assist the flood waters to reach the main river more rapidly and relieve pressure in the rivers.

The superimposed loads used in the design of these bridges were 147 lb. per square foot uniformly distributed with two knife-edge loads of 1,800 lb. per foot of width. Bridge No. 1 spans the Hundred Foot river and has an overall length of 150 ft. There are five spans of 18 ft., 35 ft., 42 ft., 35 ft., and 18 ft. respectively, the three internal spans being designed as continuous, and bitumen expansion joints are formed between the continuous portion and the free end spans. The average thickness of the slabs is 23 in., reducing to 14 in. on the end spans.

Calculations.

The following calculations indicate the method of design.

Steel stress, 16,000 lb. per square inch.
Concrete stress (150 lb. : 2 : 4 mix), 1,050 lb. per square inch.

DEAD LOAD.—

		(lb.)
Deck 23-in. average thickness		
	276 × 23	= 6,350
Parapet plinths	2 × 20 × 12	= 480
	2 × 12 × 2	= 48
Kerb	12 × 8	= 96
Road metal	16 × 20	= 320
Path	4 × 55	= 220
Parapets	2 × 50	= 100
		7,614

Say, 330 lb. per square foot.

U.D. LIVE LOAD.—

$$147 \times 16 = 2{,}360$$
$$100 \times 4 = 400$$
$$2{,}760$$

Say, 120 lb. per square foot.

KNIFE-EDGE LOAD.—

$$1{,}800 \times 16/23,$$

Say, 1,250 lb. per foot run.

Span ratio = 35/42 = 0·834 (see *Fig.* 95).

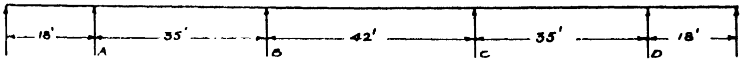

18'
35'
42'
35'
18'
A
B
C
D

FIG. 95.

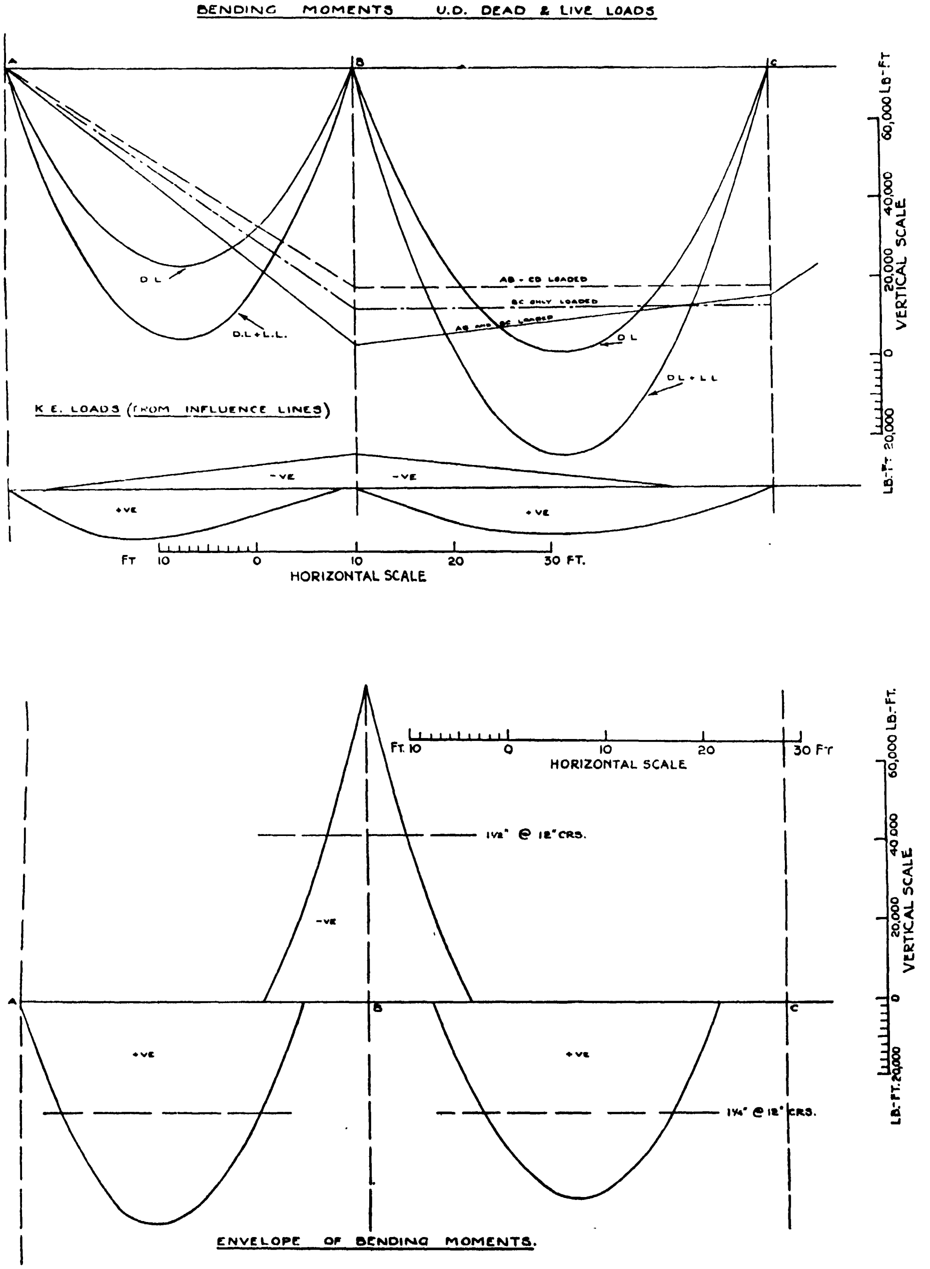

BENDING MOMENTS U.D. DEAD & LIVE LOADS
A
B
C
D L
D.L+L.L.
AB + CD LOADED
BC ONLY LOADED
D L
DL + LL
K E. LOADS (FROM INFLUENCE LINES)
-VE
-VE
+VE
+VE
FT 10 0 10 20 30 FT.
HORIZONTAL SCALE
60,000 LB-FT
40,000
20,000
0
20,000
LB-FT
VERTICAL SCALE
FT. 10 0 10 20 30 FT
HORIZONTAL SCALE
1½" @ 12" CRS.
-VE
A
B
C
+VE
+VE
1¼" @ 12" CRS.
ENVELOPE OF BENDING MOMENTS.
60,000 LB-FT.
40,000
20,000
0
LB-FT. 20,000
VERTICAL SCALE

FIG. 96.

MOMENTS.—

(lb.-ft.)

Dead load: $M_B = M_C$

$$= -\frac{1+0{\cdot}834^3}{4(1{\cdot}668+3)} \times 330 \times 42^2 = -49{,}400$$

U.D. live load: (AB and BC loaded) M_B

$$\doteq -\frac{1}{4}\cdot\frac{2(1+0{\cdot}834)0{\cdot}834^3+1+1{\cdot}668}{4(1+0{\cdot}834)^2-1} \times 120 \times 42^2 = -20{,}380$$

Knife-edge load: Span AB,

$0{\cdot}103 \times 1{,}250 \times 35 = 4{,}510$

Span BC,

$0{\cdot}08 \times 1{,}250 \times 42 = 4{,}190$

Live load: (AB and CD loaded). $M_B = M^C$

(lb.-ft.)

$$= -\frac{0{\cdot}834^2}{4(1{\cdot}668+3)} \times 120 \times 42^2 = -6{,}600$$

Live load: (BC only loaded). $M_B = M_C$

$$= -\frac{1}{4(1{\cdot}668+3)} \times 120 \times 42^2 = -11{,}350$$

		(lb.-ft.)
Moments at B:	Dead load	49,400
	Live load	20,380
	Knife-edge load	4,510
		4,190
		78,480

$$A_T = \frac{78{,}480 \times 12}{16{,}000 \times 0{\cdot}86 \times 20{\cdot}75} = 3{\cdot}3 \text{ sq. in.}$$

$R = 183.$

Use $1\frac{1}{2}$-in. bars at 6-in. centres $= 3{\cdot}53$ sq. in.

FREE MOMENTS.—

Dead load: (lb.-ft.)

$$M_{AB} = \frac{330 \times 35^2}{8} = 50{,}600$$

$$M_{BC} = \frac{330 \times 42^2}{8} = 72{,}700$$

Live load:

$$M_{AB} = \frac{120 \times 35^2}{8} = 18{,}400$$

$$M_{BC} = \frac{120 \times 42^2}{8} = 26{,}500$$

Max. positive moment in AB = 56,000 (see *Fig.* 96).

$$A_T = \frac{56{,}000 \times 12}{16{,}000 \times 0{\cdot}86 \times 20{\cdot}75} = 2{\cdot}35 \text{ sq. in.}$$

Use $1\frac{1}{4}$-in. bars at 6-in. centres $= 2{\cdot}45$ sq. in.
Max. positive moment in BC = 50,000 lb.-ft.
Use $1\frac{1}{4}$-in. bars at 6-in. centres.

FREE SLABS.—

Span = 18 ft.

	(lb.)
Dead load	7,614
Less $10 \times 12 \times 23$	2,760
	4,854
Haunch $\frac{48 \times 10 \times 23}{18 \times 2}$	307
	5,161
	(lb.)
Load per square foot =	224
L.L. =	120
	344

$$M = \frac{344 \times 18^2}{8} + \frac{1{,}250 \times 18}{4}$$

$= 19{,}640$ lb.-ft.

$$A_T = \frac{19{,}640 \times 12}{16{,}000 \times 0{\cdot}86 \times 11{\cdot}5}$$

$= 1{\cdot}49$ sq. in.

$R = 149.$

Use 1-in. bars at 6-in. centres $= 1{\cdot}57$ sq. in.

Bridge No. 2 over the Old Bedford river requires no description as the design is similar to Benwick Bridge with slight adjustments to span and widths as seen in *Fig.* 94.

Construction.

The contract for the bridge structures and earth embankments to road foundation level was let to Messrs. Tarslag (1923), Ltd., in the sum of £5,601 in April, 1938, and constructional work on both bridges is now almost complete.

In the original design 12-in. by 12-in. pre-cast concrete piles 30 ft. long were allowed, but on driving it was found necessary to increase the lengths of the piles to 35 ft. and to increase the piles to 14-in. by 14-in. section for bridge No. 1, the latter decision being arrived at in view of the length of piles acting as columns.

Fortunately there was very little water in the Old Bedford river during the construction of the bridge, and the deck formwork was built up from timber sole-plates laid in the stream bed. In the case of bridge No. 1, as there is always a considerable depth of water in the tidal Hundred Foot river, the deck shuttering had to be carried partly on temporary timber piles and partly on the permanent

timber fender piles driven to protect the pile trestles of the centre span. *Fig.* 97 shows bridge No. 2 as it is at the time of writing.

The construction of the new Benwick bridge was only recently commenced and so far the piles supporting the north-west abutment have been driven.

Trial piles 50 ft. long were driven, but after these were driven it was found possible to reduce the lengths of the remaining piles to 35 ft. as the necessary set was obtained with the pile shoes still in the gravel.

The tender of Messrs. W. & C. French, Ltd., was accepted for the bridgework in the sum of £2,720. The roadworks and embankment are now almost completed, the estimated cost being £2,156. The unit cost of Benwick Bridge is £1·05 per square foot.

FIG. 97.

WIDENING OF WOOLLEY BRIDGE, GLOSSOP

THE existing bridge carrying the Hyde–Glossop road (A57) over the river Etherow at Glossop has a span of 56 ft., but the width between its parapets is only 20 ft., which is too narrow to accommodate the traffic without causing obstruction. A scheme (*Figs.* 98 and 99) for widening the bridge and its approaches has therefore been prepared by Mr. C. G. Millican, M.Inst.C.E., County Surveyor of Derbyshire, and the work will shortly be commenced.

The existing parapet on one side of the bridge is to be pulled down and the bridge widened in reinforced concrete so as to give space for a 30-ft. carriageway and two footpaths each 15 ft. wide. The new work will include a reinforced concrete arch with a span of 56 ft. and a rise of 12 ft. from springing level to the soffit at the crown. This will be constructed on mass concrete abutments and will be 15 in. thick at the crown and 4 ft. thick at the springings. On the new downstream elevation the vault will be finished with rock-faced masonry voussoirs with 1½-in. drafted margins and 1½-in. by 1½-in. chamfers. The new spandrel walls will also be faced with rock-faced masonry, and the parapet will be of masonry to match that on the upstream side of the bridge. Between the new and the old arches a tarred paper joint will be inserted to allow the two portions to work separately. The road surfacing will be laid on weak concrete filling over the central part of the vault and on 12 in. of pitching over the haunches. Illustrations of the bridge are given on the following two pages.

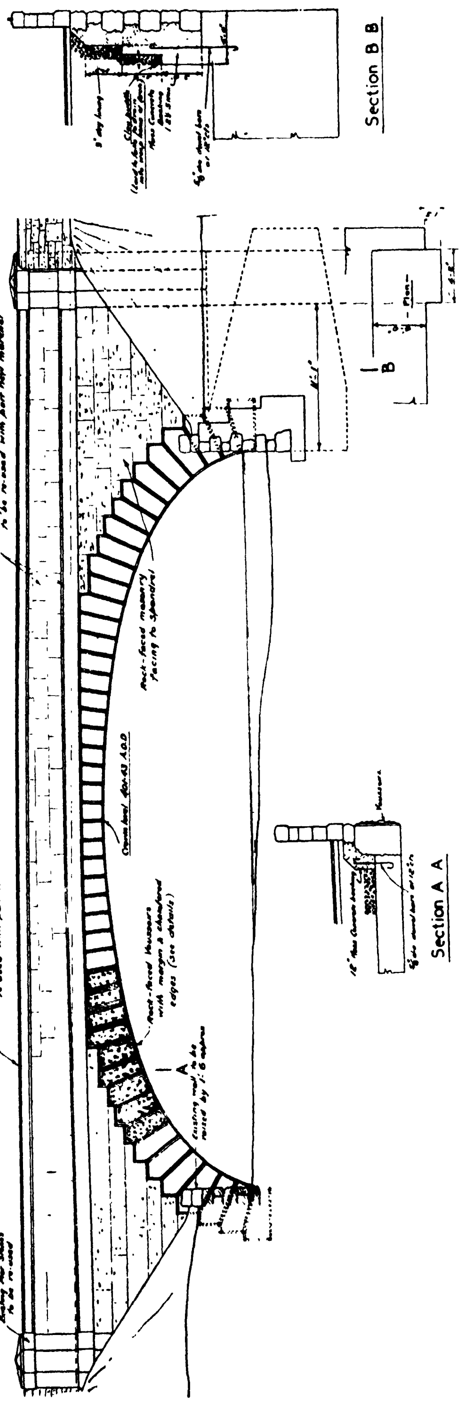


FIG. 98.—WIDENING OF WOOLLEY BRIDGE, GLOSSOP. DOWNSTREAM ELEVATION (*see previous page*).

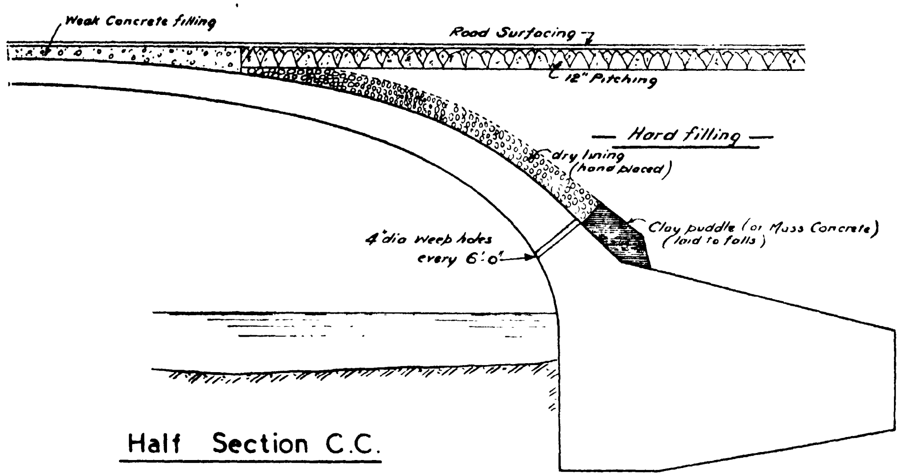


FIG. 99.—WIDENING OF WOOLLEY BRIDGE: PART TRANSVERSE SECTION (*see facing page.*)

BRIDGE ON THE CATERHAM BY-PASS ROAD

Continuous Girder Bridge with Unequal Spans.

TILLINGDOWN LANE BRIDGE on the Caterham By-pass Road is a reinforced concrete structure, and has a total length of 124 ft. and a width between parapets of 22 ft. 6 in. to provide for a 16-ft. carriageway and a 5-ft. path. It was designed by Mr. W. P. Robinson, C.B.E., M.Inst.C.E., County Surveyor of Surrey, and was constructed by direct labour.

The bridge (*Fig.* 100) was designed to carry the Ministry of Transport standard loading and carries the existing lane over the new by-pass road on a skew of 51 deg. 30 min. to the new centre line. It was designed as a continuous girder bridge of four unequal spans; the intermediate supports are trestles and the abutments are constructed with counterforts. The footpath is cantilevered beyond the parapet girder, and to provide a suitable elevation the soffit of the beams is a circular curve and the top of the beams a parabola. The elevation was approved by the Fine Art Commission.

Except for the foundations of the abutments and trestles, which had to be taken down to a chalk foundation, the concrete mix is 1 : 2 : 4. The concrete in the beams was vibrated by the needle method.

Allowance has been made for cycle tracks on the by-pass road in the future and for widening Tillingdown Lane, and the parapet railings will be easily removed when this is required.

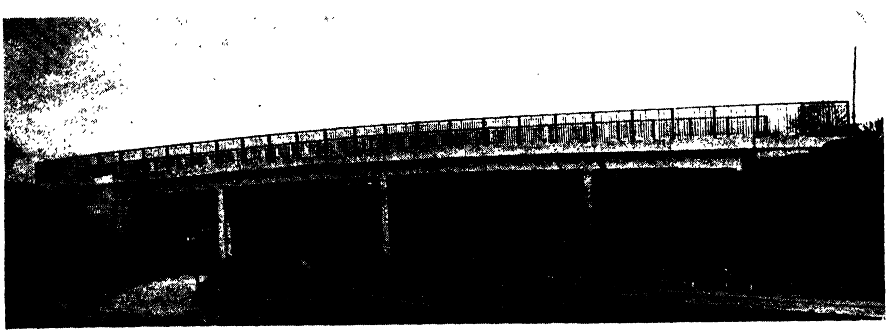


FIG. 100.—BRIDGE ON THE CATERHAM BY-PASS ROAD, SURREY.

Portal Frame of 170 ft. Span.

THE old suspension bridge across the river Dee at Aboyne, built in 1832 and of 280 ft. clear span, was characteristic of the suspension bridges erected in considerable numbers about that period. The chains consisted of wrought-iron eye-bar links with wrought-iron suspender rods supporting cast-iron cross beams. In consequence the old bridge was unfit to carry with safety modern loads; in addition, the carriageway was rather narrow and there were no footpaths. The County Council decided to replace it by a concrete bridge (*Figs.* 101 and 102) on the same site having a 20-ft. carriageway and two 6-ft. paths.

As the river is liable to very sudden and severe flooding it was essential that the new bridge should have the maximum waterway with as much clearance as possible towards the abutments and a minimum construction depth at the crown. The main river span has therefore been designed as a three-hinged portal frame of 170 ft. clear span. The construction is of the cellular type with five ribs, the interior ribs being 15 in. thick and the outer ribs 12 in. with a bottom slab 8 in. to 12 in. thick and a deck slab 7 in. to 9 in. thick. The abutment walls of this span are supported on semi-circular concrete hinges constructed of a rich mix to withstand the extremely high stresses to which they are subjected. The top hinges are of the flexural reinforced type. The depth of construction at the crown is 3 ft. and the rise of the soffit is 15 ft. 7 in.

There are also five approach arches on the south side arranged so that the spans gradually diminish in size towards the end of the bridge. Each of these is a segmental three-hinged arch with filled spandrels, the spans varying from 44 ft. to 50 ft. and the rises from 6 ft. 2 in. to 7 ft. There is one

FIG. 102.

arch opening of 17 ft. span at the north end of the bridge. All abutments and piers are of reinforced concrete and are founded on a sandy gravel. The parapets will be of pre-cast concrete blocks rubbed to a smooth finish. All other exposed concrete faces will be cast against "Keytex" corrugated paper lining attached to the shutters; after stripping, the surfaces will be rubbed or scraped down.

The total cost of the bridge, work on which has been in progress for several months, is £32,000. The bridge was designed by Messrs. F. A. Macdonald & Partners (Glasgow), Ltd., in consultation with Mr. M. Heddle, County Road Surveyor, and Messrs. G. Bennet Mitchell & Son advised on the architectural treatment. The contractors are Stewarts Estates (Aberdeen), Ltd.

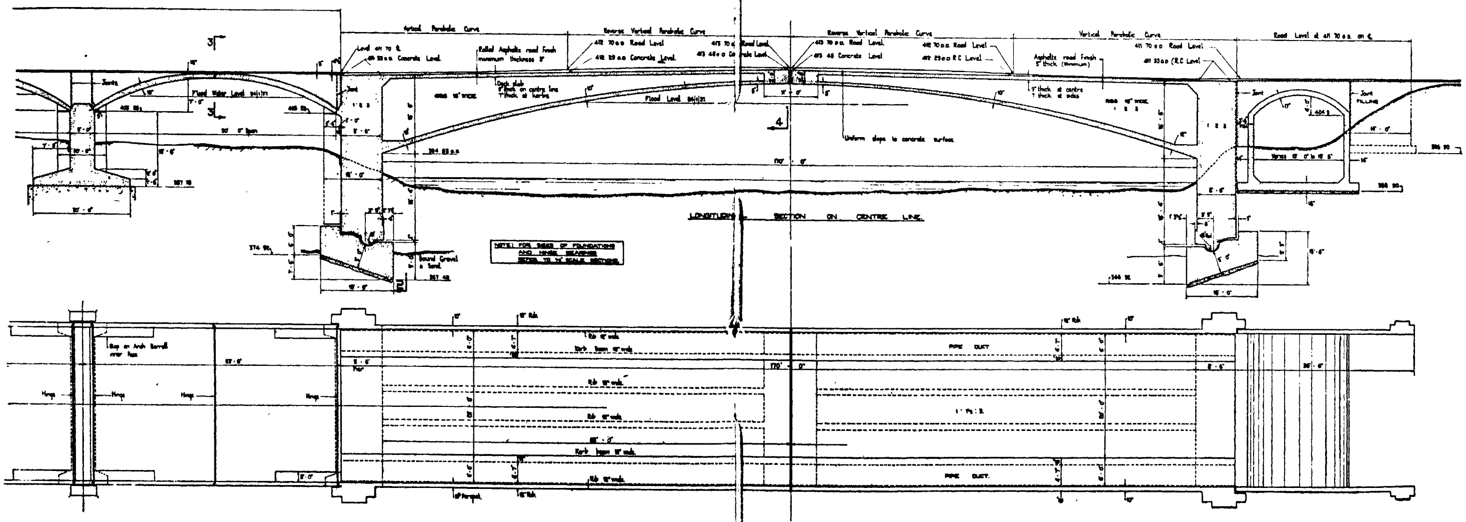


FIG. 101.

DORNIE BRIDGE, ROSS AND CROMARTY

Reinforced Concrete Bridge with Steel Bascule Span.

THE bridge which is being constructed across Loch Long between Dornie and Kyle of Lochalsh to replace the existing ferry is a low-level reinforced concrete structure containing a 40-ft. steel bascule span to allow the passage of ships up and down the loch. The bridge has been designed by Mr. James S. Cree, County Surveyor of Ross and Cromarty, in collaboration with Mr. P. Mears, F.R.I.B.A. at the middle, and will carry 2 in. of road surfacing. Between the parapets the width will be 22 ft. 6 in.; on one side only there will be a footpath 5 ft. wide. The parapets will be of reinforced concrete and extend 3 ft. 6 in. above the path level.

The whole structure, including the toll house at the Dornie end and the two reinforced concrete piers of the bascule span, will be carried on pre-cast piles 14 in. or 16 in. square according to the lengths required. The lighter piles are driven from a timber staging by a 2½-ton monkey and the heavier piles by a 4-ton monkey, with a drop of 2 ft. 6 in. in each case. A cable transporter across the loch conveys the piles and other materials from the shore. A view of the pile yard is shown in *Fig.* 104.

FIG. 103.—BRIDGE UNDER CONSTRUCTION.

The consulting engineers are Messrs. L. G. Mouchel & Partners, Ltd., and the contractors are Messrs. Wm. Tawse, Ltd. The Cleveland Bridge and Engineering Co., Ltd., are constructing the lifting span. *Fig.* 103 is a general view of the work in progress.

The piers of the reinforced concrete section are at about 45-ft. 4-in. centres, and there will be eight spans on one side of the bascule and seven on the other side. Each span has two 32-in. by 32-in. main girders and cross girders 14 in. wide by 20 in. deep at 9-ft. centres. The slab is 9 in. thick at the sides and 11 in. thick

In each pier there are three piles to carry each main beam and when driven a pre-cast shell of pentagonal shape and 5 in. thick is sunk into the sand to enclose the group. This shell is in strakes 5 ft.

FIG. 104.—PILE SKELETONS AND MOULDS.

to 6 ft. high and has overall dimensions in plan of 6 ft. 8 in. by 7 ft. 1 in. The two sides of the pentagon which are visible from the up- and down-river sides meet at an angle of 60 deg. to form a cutwater. The columns carrying the main beams are supported directly on the piles.

The relative heights of the structure and tide levels are: Roadway + 19·50 O.D.; H.W. + 8·23 O.D.; L.W. − 7·79 O.D. The pile heads finish at − 3·00 O.D. and just above this there is a horizontal brace connecting the two columns in each pier.

To carry the bascule spans there are two piers 39 ft. 5 in. by 24 ft. 1 in. in plan, protected by timber dolphins at the ends and fendering on the inner sides. The lower part of the wall of the pier is formed by the 16-in. by 16-in. bearing piles, which carry all the vertical load, with two 10-in. by 20-in. reinforced concrete sheet piles between each two 16-in. piles. The sheeting piles retain the rubble filling in the heart of the pier and extend up to − 1·50 O.D. Above this, at + 1·50 O.D., is the 14-in. floor of the machinery chamber. The lifting machinery is suspended from the deck of the pier.

LONG BRIDGE, LLANIDLOES

Widening in Reinforced Concrete.

FIG. 105.

THE old bridge over the river Severn at Llanidloes consisting of three masonry arches, two 40-ft. spans and a central 50-ft. span, has been widened by 12 ft. 6 in. on the upstream side in accordance with the designs of Mr. W. Owen Jones, M.I.M. & Cy.E., County Surveyor of Montgomeryshire. The contractors were Messrs. Davies Bros., of Barmouth.

The masonry cutwaters, spandrels, parapets and approach walls on the upstream side were removed, leaving the voussoirs in position. The parapet wall on the downstream side was also taken down to the level of the underside of the string-course.

The inverts and the foundations of the widened portion are of mass concrete, the cutwaters are of mass concrete with the original masonry facing, and the new vaults are of reinforced concrete, 24 in. thick at the crown, chamfered on the lower edge and bush hammered on the face. The mixture for the reinforced concrete in the vaults was 120 lb. of Portland cement to 2 cu. ft. of sand and 4 cu. ft. of coarse aggregate. Six weeks were allowed to elapse after concreting before any centering (*Fig.* 106) was removed.

The concrete arches are covered with a two-layer mastic asphalt waterproof coating of $\frac{3}{4}$ in. total thickness, and above this is approved dry river gravel filling. The old masonry has been re-used in the new spandrel walls and for the outer faces of the parapet walls, but the inner faces of the parapet walls are built in new masonry.

The widened bridge (*Fig.* 105) now carries a 20-ft. carriageway and two 5-ft. footways. The cost of the work was £5,220.

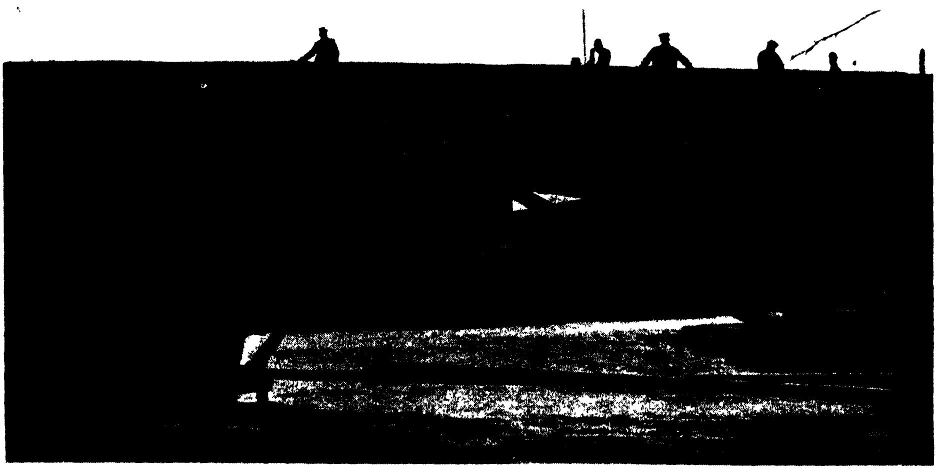


FIG. 106.

ELLON BRIDGE, ABERDEENSHIRE

Skew Bridge with three 62-ft. 6-in. Spans.

THIS important bridge over the river Ythan in the burgh of Ellon is on the Perth–Aberdeen-Inverness trunk road (A92), control of which is now vested in the Ministry of Transport. The old bridge, a three-span stone arch structure built about 1793, is only 16 ft. wide between parapets and is very hump-backed, and the south approach is very steep and tortuous. To improve the section of road it is necessary to build a new bridge connecting with the existing road immediately to the north of the old bridge and crossing the river on a skew of 24 deg.

The new bridge (*Fig.* 107), a reinforced concrete structure, will have three main spans each 62 ft. 6 in. (effective span) with two approach spans of 28 ft. and 10 ft. on the south side. The arrangement adopted is a system of seven continuous girders at 6-ft. 10-in. centres. The soffits of the girders will be curved and give the appearance of segmental arch ribs, while the rises from springing to crown will vary from 12 ft. $1\frac{1}{2}$ in. in the case of the south span to 7 ft. $11\frac{1}{2}$ in. for the north, thus enabling the bridge deck to be formed at a grade of 1 in 30. The ribs are to be 14 in. thick and the depths at mid-span 5 ft. 2 in. overall. The undersides of the ribs will be exposed and the deck slab will form a top flange. This slab will be cambered from $8\frac{1}{2}$ in. to $11\frac{1}{2}$ in. below the roadway, and below the footpaths it will be 7 in. thick and sunk to provide service ducts 24 in. deep. The width between the parapets is to be 40 ft., giving a 22-ft. carriageway and two 9-ft. footpaths, and the bridge will be carried on concrete piers and abutments faced with granite masonry to springing level. The foundations will be piled with 14-in. by 14-in. reinforced concrete raking piles driven to a batter of 1 in 6. The parapets will be concrete with vertical flutings relieved by granite ashlar panels, the cope being of pre-cast concrete with an exposed aggregate finish. An elevation of the bridge is shown in the illustration.

The total estimated cost of the work, which has just been commenced, is £30,000, and the contractors for the bridge are Messrs. W. J. Anderson, Ltd. The consulting engineers for the bridge are Messrs. Tawse & Allan, and Mr. M. Heddle is the County Road Surveyor and Engineer.

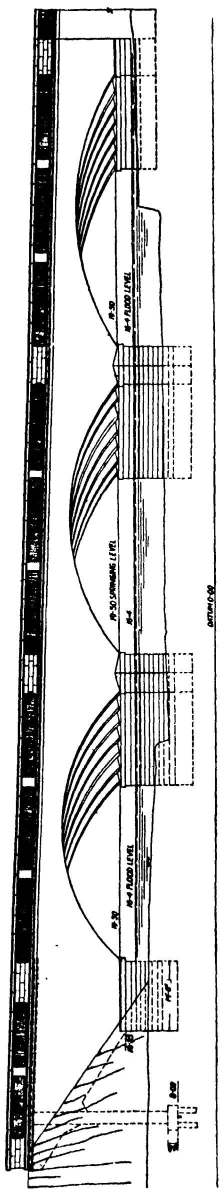


FIG. 107.—DOWNSTREAM ELEVATION, ELLON BRIDGE.

WIDENING OF PENTRE BRIDGE, MOLD

Provision for further Widening.

FIG. 108.

THIS bridge widening (*Fig.* 108) forms part of an improvement scheme for the main road A549 entering Mold from Buckley and Chester. There were two existing stone arch bridges similar in span, size, and construction, one spanning the river Alyn and the other spanning the tail race of a mill stream. It was decided to widen the old bridge spanning the river from an existing width of about 19 ft. between the parapet walls to 42 ft. so as to accommodate a 22-ft. carriageway, capable of being widened to 30 ft. in the future, and two 6-ft. footpaths. It was also decided to demolish the old bridge spanning the mill race and replace it by a rectangular reinforced concrete culvert 10 ft. by 5 ft. in section.

The bridge was widened in the form of a reinforced concrete arch of 33 ft. span at the springing level, 2 ft. thick at the springing, 12 in. at the crown, and having a rise of 9 ft. 4½ in. The foundations are built in mass concrete. The elevation of

FIG. 109.—CENTERING FOR ARCH.

the arch ring, the stringcourse and the coping of the parapet walls were faced with Darley Dale sandstone, and the rest of the elevation of the widened portion was faced with weathered and squared limestone taken from some old buildings in the neighbourhood. The facing stonework was backed with mass concrete.

The main reinforcement in the arch is ¾-in. bars at 6-in. centres and the distribution steel is ½-in. bars at 6-in. centres. The contour of the intrados of the reinforced concrete follows the line of the old bridge as far as possible. A mastic joint was placed between the old and new work, and the extrados of the new arch was covered with ¾ in. of asphalt in two coats. Views of the construction are illustrated in *Figs.* 109 and 110, the former showing the bolted timber centres with 1½-in. spruce lagging, and the latter showing the reinforcement fixed and the voussoirs in position.

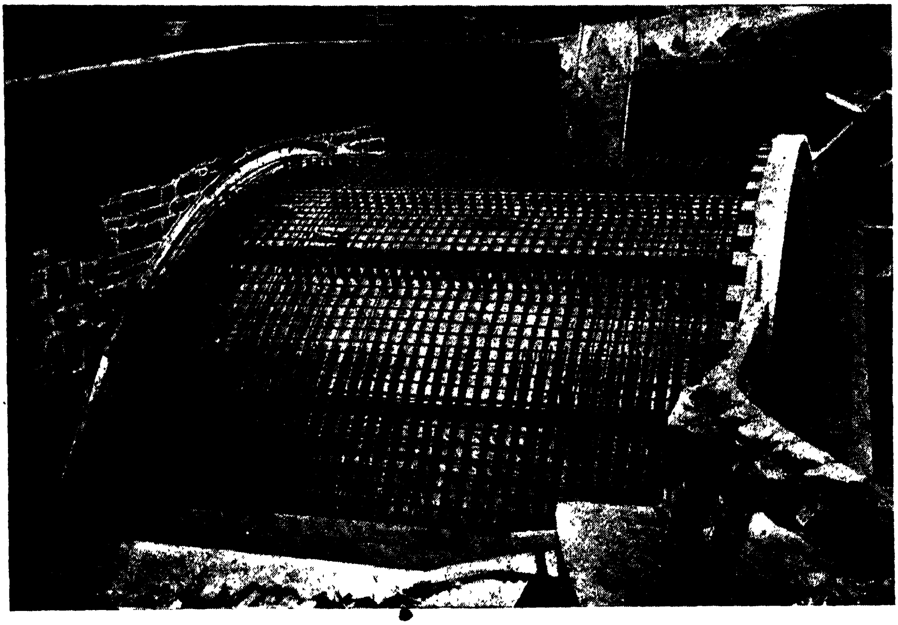


FIG. 110.—REINFORCEMENT AND VOUSSOIRS IN POSITION.

The plans and detailed designs for the whole of the bridge widening, new culvert, and road widening were prepared in the office of the County Surveyor, Mr. R. G. Whitley, A.M.Inst.C.E., and the work was carried out by direct labour.

BRIDGE OF FEUGH, KINCARDINESHIRE

Three-hinge Barrel Arch of 89 ft. Span.

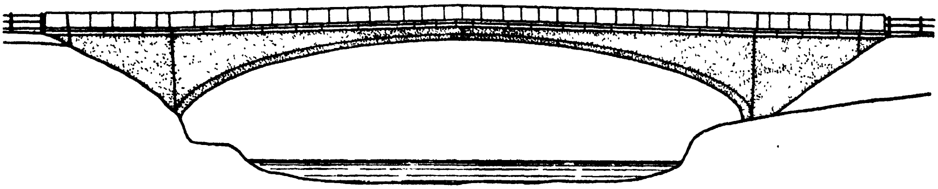


FIG. 111.

THIS bridge has been designed to carry route A943 across the river Feugh, a swift and turbulent mountain stream in Kincardineshire, at a point just before it joins the river Dee. The design consists of a single-span reinforced concrete three-hinge barrel arch. The clear span is 89 ft. with a rise of 12 ft., and the arch is supported on mass concrete abutments. The concrete spandrel walls are to be bush-hammered or to receive other treatment to improve the appearance of ordinary concrete. The parapets are to be of granite.

In order to avoid supporting the centering from the bed of the stream, light structural steel ribs are to be erected first to carry the formwork. The ribs are designed as lattice trusses with pin joints at the crown and springings. In all there will be fifteen complete trusses, and these will be spaced at 3-ft. 2-in. centres except at the crown where the spacing will be reduced to 1 ft. 6 in. on either side of the longitudinal centre line of the bridge. In each rib the top and bottom flanges will be alike in cross section and composed generally of two 3½-in. by 3½-in. by ⅜-in. angle irons, which will be spaced ⅜ in. apart to allow the single system of lattice bracing of 2½-in. by ⅜-in. flats to pass between the vertical legs of the angles. Pairs of 3-in. by 2½-in. by ⅜-in. angles with ⅜-in. packing pieces will be inserted at intervals at right-angles to the flanges so as to divide the ribs into panels. Angle irons, 4 in. by 4 in. by ⅜ in. in section and curved to follow the soffit of the arch ribs, will be suspended 4½ in. below the bottom flanges of the ribs to carry the 2½-in. planking forming the shuttering of the arch. In this way the cover of concrete in the soffit of the flanges of the ribs will be made 2 in. thick. An equal thickness of concrete will cover the top flanges of the ribs.

The authority responsible for the bridge (*Fig.* 111) is the County of Kincardine, whose engineer is Mr. Eric Moir. Messrs. F. A. Macdonald & Partners (Glasgow), Ltd., are the consulting engineers, and the collaborating architect is Mr. F. C. Mears, F.R.I.B.A.

MOSS ROAD BRIDGE, STRETFORD

In Situ Piling.

THE recently-completed reinforced concrete bridge over the Bridgewater Canal at Moss Road, Stretford, has replaced a stone arch bridge constructed in 1785. The new bridge (*Fig.* 112) has a clear span of 45 ft. and is 48 ft. wide between parapets, allowing for a 30-ft. carriageway and footpaths 9 ft. wide. The new elliptical skew span arch has an effective span of 48 ft. and a rise-span ratio of 1 : 11. The reinforcement is of the rigid pre-erected type from which the shuttering was suspended. Hinged joints are provided at the springing points of the arch reinforcement, around which keyways were formed and kept open until the arch slab had been completely cured.

The abutments are of the cellular type resting on 70 in-situ piles 15 in. diameter taken down an average depth of 23 ft. to a deep seam of compact ballast. As one abutment formed part of the canal training wall, fenders of 12-in. by 4-in. creosoted pine planks were secured thereto

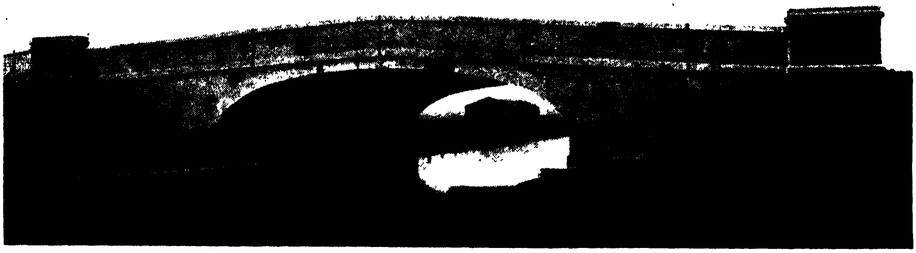


FIG. 112.—MOSS ROAD BRIDGE, STRETFORD.

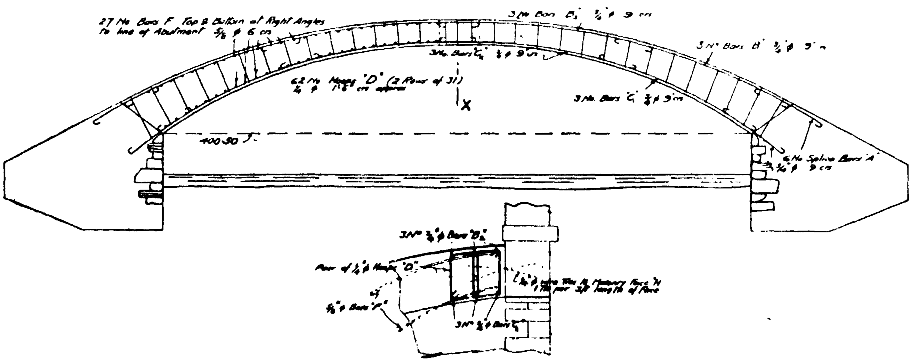
by means of rag-bolts. Expansion joints are provided in the parapet walls immediately over the springing of the arch, and intermediate contraction joints are also provided. The shuttering was made from 1-in. tongue-and-groove boarding, and the concrete mixture was $3\frac{3}{4}$ cu. ft. of $\frac{3}{4}$-in. to $\frac{3}{8}$-in. washed gravel, $1\frac{1}{4}$ cu. ft. of $\frac{3}{8}$-in. to $\frac{3}{16}$-in. washed gravel, $2\frac{1}{2}$ cu. ft. of Mersey sand, and 112 lb. of cement.

The scheme was prepared by Mr. Edwin Parker, M.Inst.M. & Cy. E., the Borough Engineer and Surveyor, in collaboration with Messrs. Ritchie and Partners, and was carried out at a total cost, including road works, of just over £9,500 under the supervision of Mr. E. G. King, A.M.Inst.C.E., of the Borough Engineer's staff. The contractors were Messrs. Bethell & Sons, Ltd., and the Franki Compressed Pile Co., Ltd., acted as sub-contractors for the piling.

SEATHWAITE BRIDGE, CUMBERLAND

THIS bridge is situated in the Lake District in the vicinity of Keswick, Seatoller, and the famous Honister Pass. The bridge spans the river Derwent and carries the unclassified road from Seatoller to Seathwaite, where the road, so far as ordinary traffic is concerned, terminates. Seathwaite is the starting place for climbers.

The existing bridge was only 12 ft. wide and was out of keeping with the district, being constructed of steelwork with sleeper decking and tube handrails. The angles of approach were also exceedingly awkward and there was a gate across the road on the north side of the bridge.



SECTION X-X

FIG. 113.—SEATHWAITE BRIDGE, CUMBERLAND.

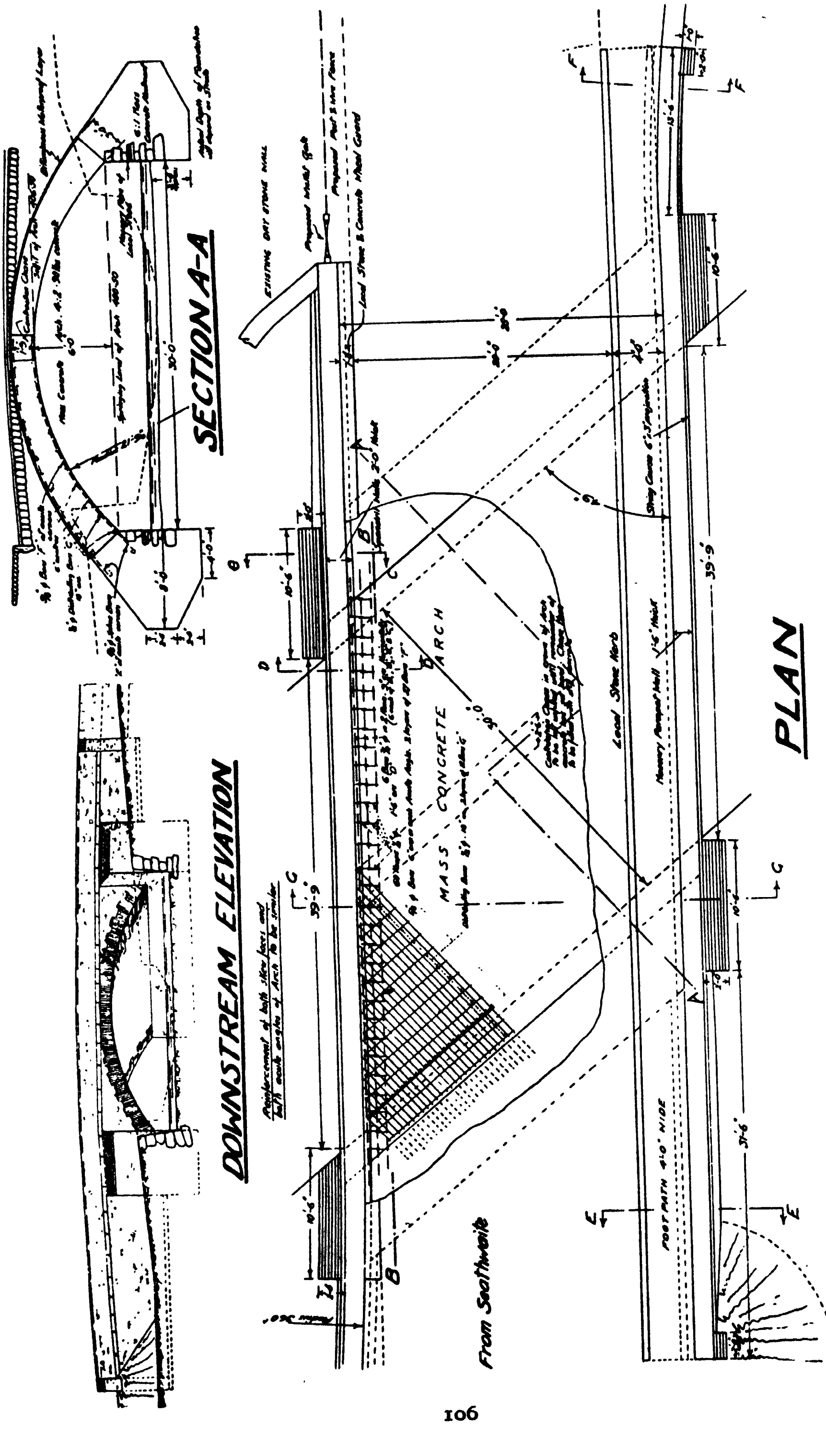


FIG. 114.—SEATHWAITE BRIDGE.

The new bridge (*Fig.* 113) is a reinforced concrete skew arch, 30 ft. span, designed to carry the Ministry of Transport Standard Loading, and is faced with greyish green local stone. It is 25 ft. wide between the parapets and carries a 20-ft. road, a 4-ft. pathway, and a guard strip 12 in. wide. Details of the mass concrete arch and the skew reinforcement are shown in *Fig.* 114.

Considerable improvement has been effected in the alignment of the structure; the gate across the road has been removed, this having been made possible by fencing in the open fell land with an unobtrusive type of post-and-wire fence.

The road on which this bridge is situated has been considerably improved during recent years on account of the considerable amount of tourist traffic using it in the summer. Previously it was impossible for two cars to pass except at certain odd places, but this has now been remedied.

The estimated cost of the work was £1,100, towards which the Ministry of Transport made a 50 per cent. grant. The scheme was designed by the technical staff under the supervision of Mr. G. O. Lockwood, M.Inst.C.E., F.S.I., County Surveyor and Bridgemaster of Cumberland, and the work is being carried out by direct labour.

LINLITHGOW BRIDGE

Cellular Abutments.

THIS bridge is to be constructed at the point where the A9 road crosses the river Avon in the town of Linlithgow. The bridge (*Fig.* 115) will consist of a main span and three approach spans, the main span being a skew filled-spandrel barrel arch 21 in. thick at the crown and the approach spans curved rib construction to give an external appearance of arches with spans of 22 ft. 6 in., 26 ft. 6 in., and 30 ft. The main span is 108 ft. clear, with a rise of 18 ft. Between the parapets the width will be 50 ft.

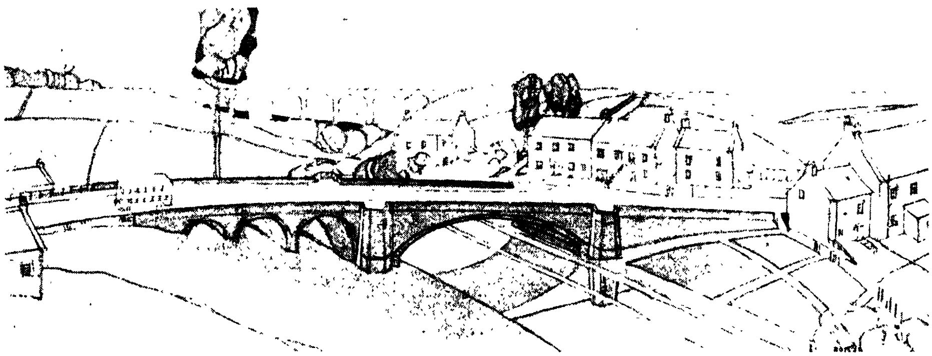
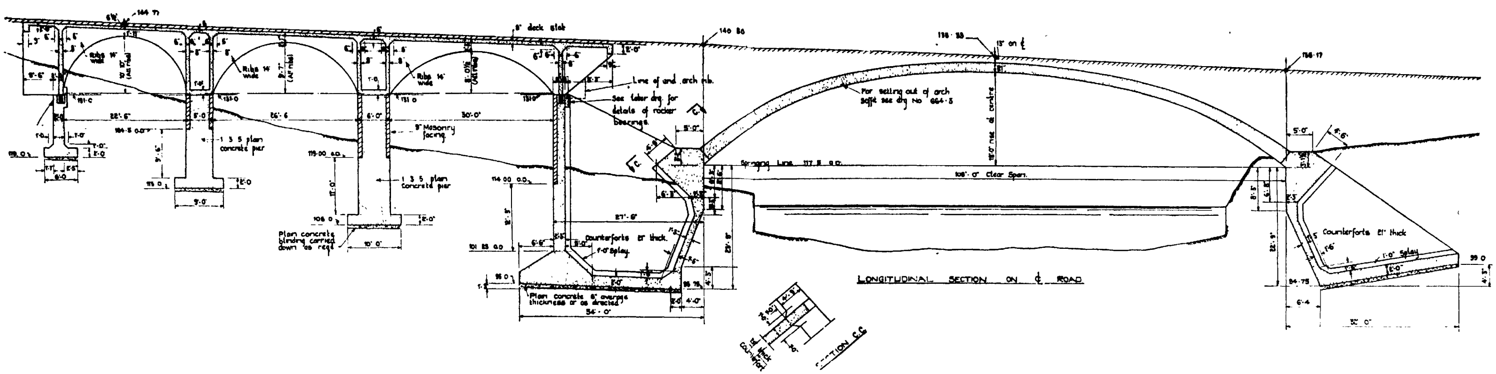


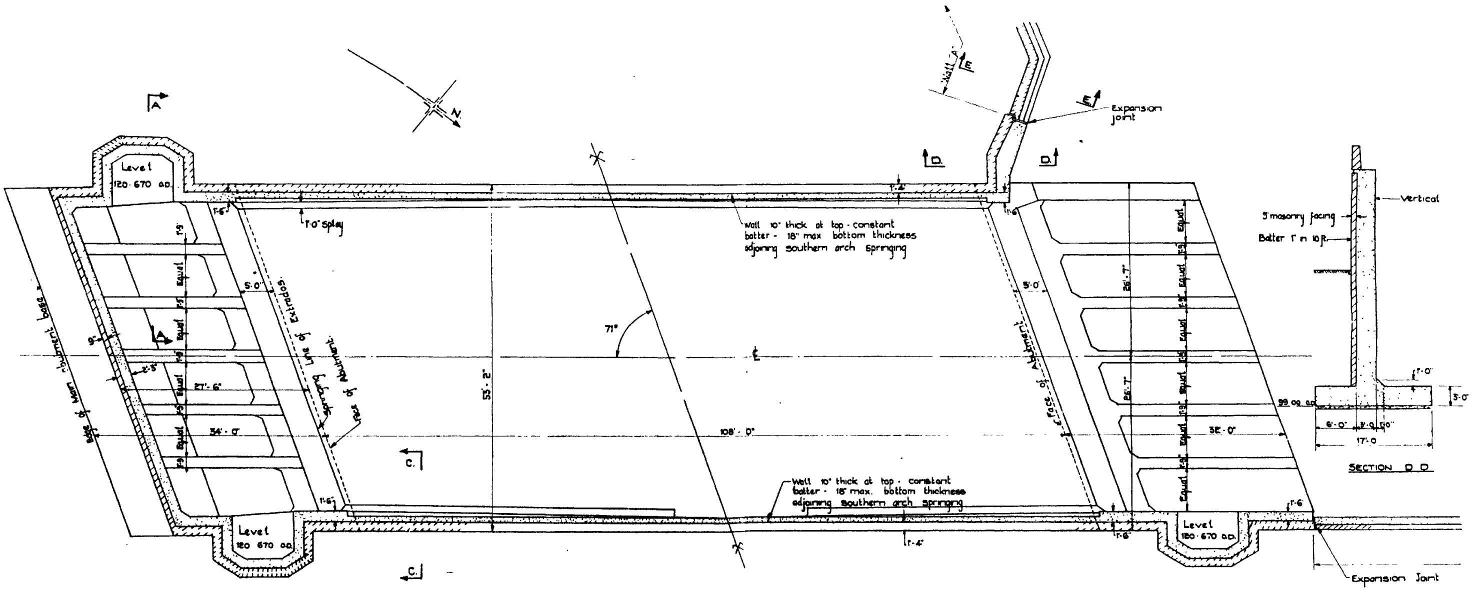
FIG. 115.

A relatively unusual feature of the design is that the main abutments are of cellular construction. A longitudinal section on the centre line of the road and part of the plan, with the roadway removed, are given on the next page. Rocker joints will be placed between the three approach spans and the main span in order to allow a certain degree of movement between the two parts of the structure in view of the different methods of construction in each. The whole of the structure will be faced with natural stone to match the existing stone buildings adjacent to the bridge.

The bridge has been designed by Messrs. F. A. Macdonald & Partners (Glasgow), Ltd., and the collaborating architect is Mr. J. H. Fraser Stewart, L.R.I.B.A. The responsible County Road Surveyors are Mr. John Schoolar, M.Inst.M. & Cy.E., of Stirlingshire, and Mr. A. M. Smith, of Linlithgowshire.



SECTION ON CENTRE LINE OF ROADWAY.



PLAN WITH ROADWAY REMOVED.

FIG. 116.—LINLITHGOW BRIDGE.

BRIDGE OVER THE RIVER COLE

Accommodating a 30-in. Water Main.

THE proposed reinforced concrete arch over the river Cole at Highfield Road, Yardley Wood, Birmingham, will replace an existing three-span brick arch bridge.

The width of the existing bridge is 16 ft. between parapets, whereas the new structure will accommodate two 24-ft. carriageways, two 12-ft. 6-in. footways, and a central reservation 7 ft. wide, making a total overall width of 80 ft. between parapets.

The new structure, which is designed for Ministry of Transport loading, will be a fixed reinforced concrete segmental arch with solid abutments having a clear span of 35 ft. and a rise of 7 ft. 6 in. The thickness of the vault (*Fig.* 118) will be 12 in. at the crown and 18 in. at the springings, and the radius of the soffit will be 24 ft. 2 in. At 9 ft. on either side of the crown there will be a shrinkage key 3 ft. long. Within the portion of the vault bounded by these keys the longitudinal reinforcement will be $\frac{3}{4}$-in. bars at 6-in. centres, and from the key to the abutments $\frac{7}{8}$-in. bars at 6-in. centres. The distribution bars will be $\frac{1}{2}$-in. diameter at 12-in. centres on both intrados and extrados. The spandrels and wing walls are to be of mass concrete construction faced with sand-faced brickwork, while the parapets will be constructed of Clipsham stone. The wing walls will be curved to suit the wide footway reservations in the approaches, which have been planned to include grass verges, hedges and trees.

A notable feature of the bridge design is the accommodation of a 30-in. diameter water main in the central reservation. The existing main is syphoned under the river bed on the south side of the existing bridge and, as the new bridge foundations have to be carried to a depth sufficient to allow of later river deepening, it is necessary to find accommodation for this main over the new structure. A considerable saving in constructional depth

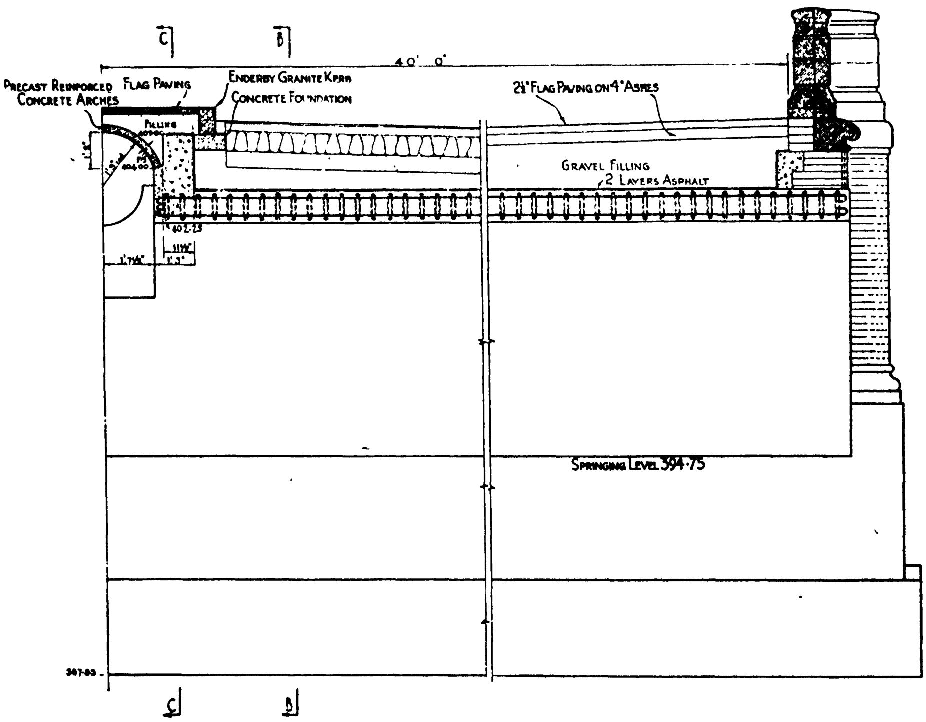


FIG. 117.—SECTION THROUGH CENTRE OF ARCH.

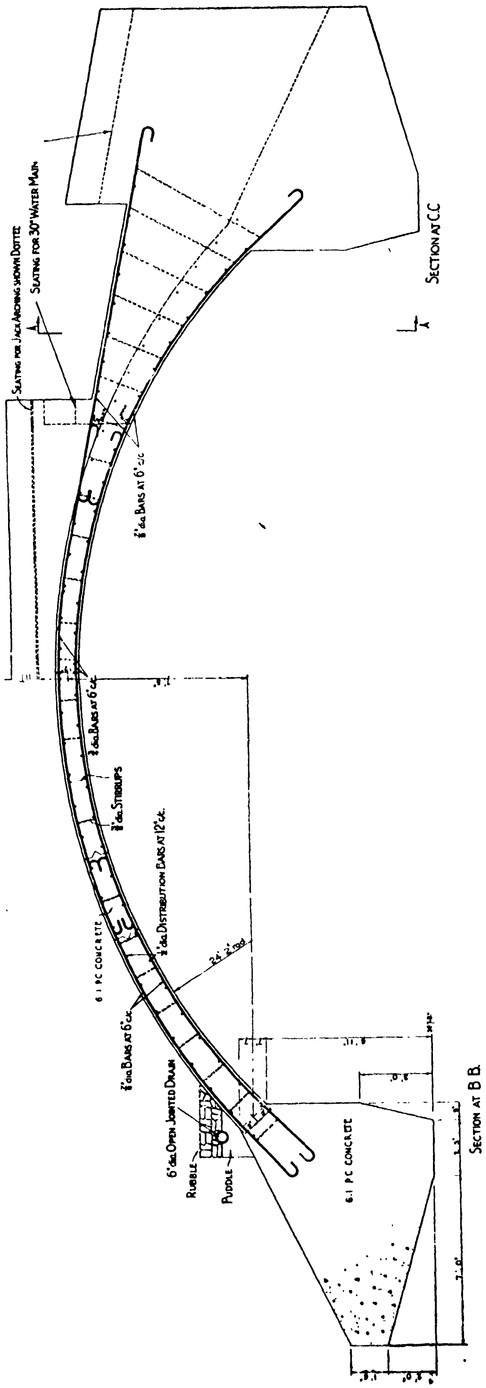


FIG. 118.—PROPOSED BRIDGE OVER THE RIVER COLE.

is effected by diverting the line of the main and dividing the arch in order that the 30-in. steel pipe may be supported with its underside flush with the highest level of the arch intrados (*Fig.* 117). Facilities for inspection and renewal of the pipe are provided by means of pre-cast reinforced concrete jack arches to carry the filling for the central reservation.

By the adoption of this method, in preference to the usual procedure of providing the accommodation under the footway, the depth of the spandrel walls over the arch is reduced, as a consequence of which better proportions in the elevation are obtained and a considerable saving in dead load effected.

The design for the new bridge was carried out by Mr. Herbert J. Manzoni, M.Inst.C.E., City Engineer and Surveyor of Birmingham. The estimated cost of the reconstruction scheme, including approaches, alterations to mains, and acquisition of property, is £17,300.

FOOTBRIDGE AT NORTH SHEEN

Reinforced Concrete Slab between Parapet Girders.

A FOOTBRIDGE now under construction across the Southern Railway at North Sheen, between Kew Gardens Station and Manor Circus, has been designed by Mr. J. W. Trodd, A.M.Inst.C.E., Borough Engineer of Richmond. The bridge (*Fig.* 119) is of reinforced concrete, and the consulting engineers are Messrs. L. G. Mouchel & Partners, Ltd. Mr. A. E. Farr is the contractor.

FIG. 119.—FOOTBRIDGE OF 68 FT. 8 IN. SPAN AT NORTH SHEEN: FALSEWORK ERECTED.

In plan the structure is L-shape, one staircase being parallel to the railway line and the other in continuation of the 68-ft. 8-in. clear span. Between the parapets the width is 6 ft. The bridge was designed for a superimposed load of 112 lb. per square foot. The floor is a reinforced concrete slab 6½ in. thick at the middle and 5½ in. thick at the edges and is to be covered with asphalt. It spans between the parapets, which are the main girders of the 68-ft. 8-in. span, and is stiffened by four 8-in. by 8-in. (net) cross ties under the floor. Between rail level and the underside of the floor the minimum headroom is 15 ft. 6 in. The parapet girders extend 5 ft. 6 in. above the floor level and have a total depth of 7 ft. and a width of 10 in. At the midspan they are reinforced with twelve 1⅜-in. bars in the bottom and a like arrangement in the top. At the ends they are carried on trestle piers each formed of four 18-in. square columns, and the whole is supported on a concrete footing 9 ft. square.

Over the 25-ft. 6-in. width of the loading gauge on the two running tracks, the shuttering is carried on two 18-in. by 6-in. by 55-lb. rolled steel joists supported on timber trestles at the ends and carrying on their bottom flanges the 6-in. by 3-in. timber joists which support the 1¼-in. sheeting under the floor slab. Vertical cleats, 6 in. by 2 in. in section, with the bolts and spacers at the top, hold the longitudinal sheeting of the outer formwork of the parapet girders.

THE INVERSCADDLE BRIDGES, ARGYLLSHIRE

Suspended Spans on Cantilevers from Piers.

ROAD development in the Western Highlands has to a large extent naturally followed the seaboards of the sea-lochs which cut deeply into the country in a north-easterly direction between the intervening mountain ranges. The watershed is for the most part short and rapid and there are few large rivers to be crossed.

One of the latter occurs at Inverscaddle, about four miles north of Ardgour, where a new diversion is in course of construction to eliminate over half a mile of obsolete roadway and a weak bridge on a dangerous alignment. The river Scaddle is tidal up to about half a mile above the crossing, and when a spring tide is combined with a south-west gale and the river is in spate extensive flooding occurs around the estuary. In normal conditons the river occupies a well-defined main channel, but when in spate it turns into a wide overflow channel separated from the main stream by a small island of higher ground. Both river and overflow will be crossed by reinforced concrete slab structures of similar type now in course of erection.

The river will be crossed by a three-span structure (see *Fig.* 120) consisting of reinforced concrete slab end spans, free but counterbalanced at the abutments, cantilevering over the river piers and carrying a suspended centre span. The end spans are 26 ft. to the centre of the pier and vary uniformly in thickness from 11 in. at the abutment to 31 in. over the pier. Thereafter the cantilevered section projects 9 ft. and terminates with an overall thickness of 23½ in. at the suspension joint, the system being reinforced with 1⅛-in. bars as shown.

The suspended section, with an effective span of 24 ft. and a central thickness of 21⅛ in., will be carried on a series of bearing plates 10½ in. by 6 in. in plan, consisting of ¼-in. mild steel plates sandwiching with two ⅛-in. copper plates, the plane between the copper plates being lubricated with graphite and the sets adequately protected from subsequent corrosion. One end of the span will be free and the other anchored by dowel bars passing through the bearing plates. Bearings on the inside of the curve will be given an opposite cant to the others so as to provide a wedging action against lateral movement in the suspended slab.

The abutment ends of the side spans will be anchored, without fixing moment, to the mass concrete abutments which will be provided with a lacing reinforcement, the mass acting as a counterpoise under certain applications of live load. The piers, also, will be of mass concrete, and where considered necessary tongue walls about 2 ft. wide will be sunk below general foundation level as an additional protection against the possibility of scour.

In design, the proportioning of the widths of side to centre span received consideration and it was found that both structurally and æsthetically the most pleasing results were obtained by dividing them in a ratio approximating to the "Golden Section." A light open parapet was adopted, so as to preserve the slender appearance of the superstructure. A simple cast-iron standard and tubing parapet was adopted. With this, provision for expansion will be made at couplings and at the terminal lengths of concrete parapet over the headwalls.

No special provision has been made for the surface finish of the concrete; this will be untouched after removing the shuttering.

The construction of the bridge across the Scaddle overflow follows the same principle as that across the river, the system being extended to give a 26, 42, 42, 42, 26 ft. span arrangement. The centre span is continuous with its cantilevered ends, and for appearance the soffit is similar in shape to that of the adjacent spans even though this necessitates heavy reinforcement, 1¼-in. bars being used at 4½-in. centres in the top and 3-in. centres in the bottom. Training embankments with stone-pitched faces will be constructed from the abutments for a distance of about 50 ft. upstream in order to discourage possible scour alongside the road embankments during spates and receding floods.

The works were designed by the staff of the County Engineer, Mr. G. Wishart, B.Sc., M.Inst.C.E., and the contractors are Messrs. W. & G. Anderson, Ltd., who are carrying out the work at an estimated cost of £1,700 for the Scaddle bridge and £2,150 for the overflow bridge.

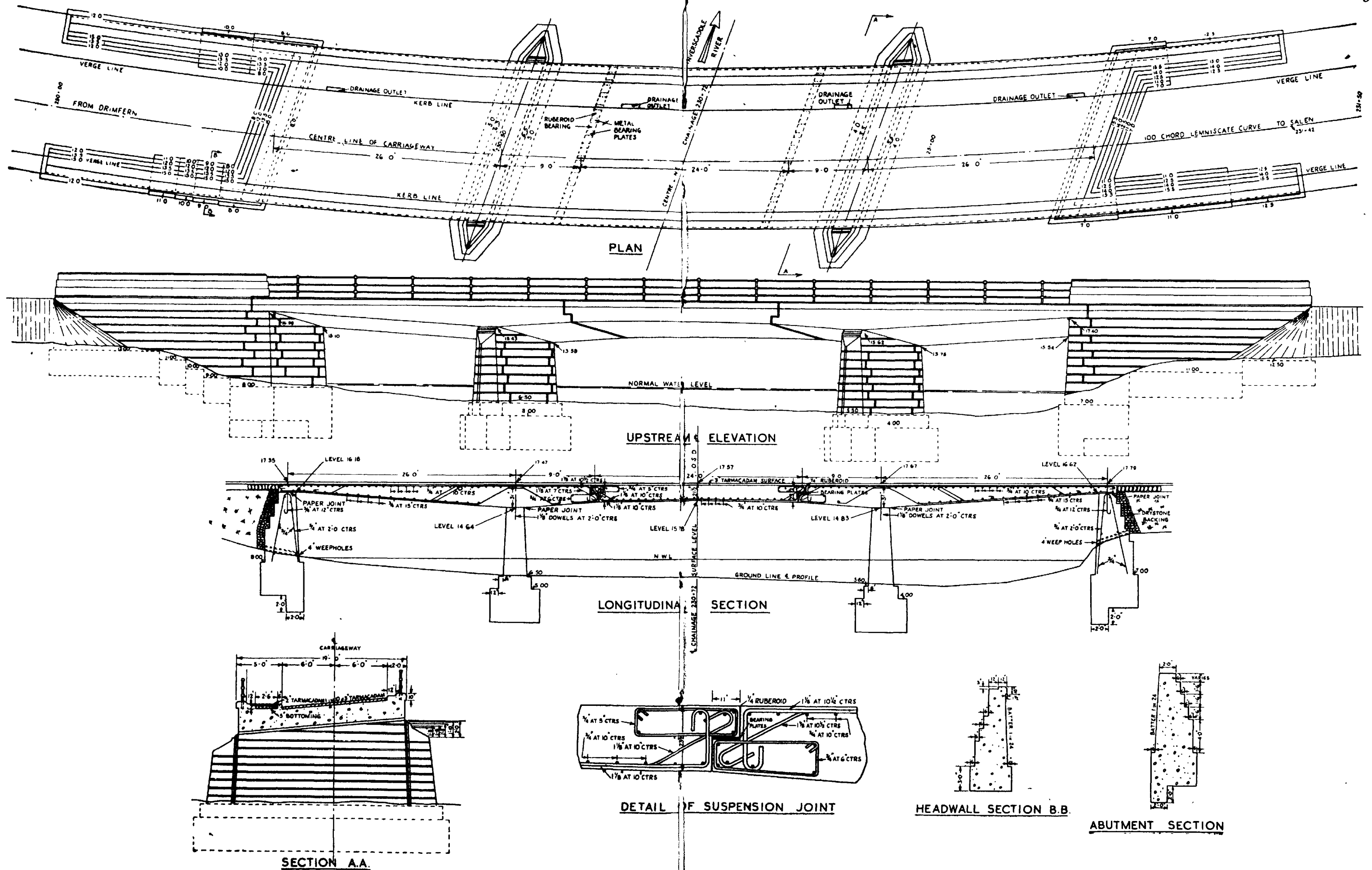


FIG. 120.—INVERSCADDLE BRIDGE, ARGYLLSHIRE.

BRIDGES IN SCOTLAND DESIGNED BY THE MINISTRY OF TRANSPORT

ALL the bridges described in the following were designed and the drawings made in the office of the Chief Supervising Engineer, Ministry of Transport, Oban, under the supervision of the Divisional Road Engineer for Scotland. They form part of the Crofter Counties Special Financial Assistance Scheme, and have all been approved by the Fine Arts Commission, Scotland. Provision is made in each case for the future extension of public services, such as cables, water pipes, etc., and for widening.

FIG. 121.—AWE BRIDGE.

AWE BRIDGE.

150-ft. Hollow-Spandrel Arch.

Awe bridge (*Fig.* 121) is an arch of 150 ft. span, crossing the river Awe at the west end of the Pass of Brander on the Tyndrum–Oban road (A85). The bridge, of which a longitudinal section is shown in *Fig.* 122, is of hollow-spandrel design with the roadway carried on reinforced concrete spandrel walls 2 ft. 6 in. thick (including the masonry facing) and on eight transverse beams 18 in. deep by 12 in. wide. These beams have two equal clear spans of 11 ft. and each is continuous over a reinforced concrete pillar, 30 in. by 12 in. in cross section. The pillars are arranged along the centre line of the arch and transmit their loads to the arch barrel through footing beams 8 ft. 6 in. wide by 2 ft. deep. The total width from outside to outside of the spandrel walls is 29 ft. 6 in. In the spandrel walls the reinforcement consists of two meshes of bars at 12-in. centres horizontally and vertically.

The reinforced concrete deck slab spanning between the transverse beams is 12 in. thick below the centre line of the carriageway and 9 in. thick below the kerbs. Its clear spans are 7 ft., 8 ft., 8 ft., 8 ft., and 7 ft. at each end of the bridge, and the reinforcement consists of ⅞-in. bars at 16-in. centres in the middle of the spans and at 8-in. centres over the supports. In the middle of the bridge the deck is a continuous saddle 64 ft. long which is carried directly on the extrados of the arch barrel. At the ends of this saddle there is an expansion joint in the deck slab.

The clear span of the arch barrel is 147 ft. 11¾ in. and the effective span

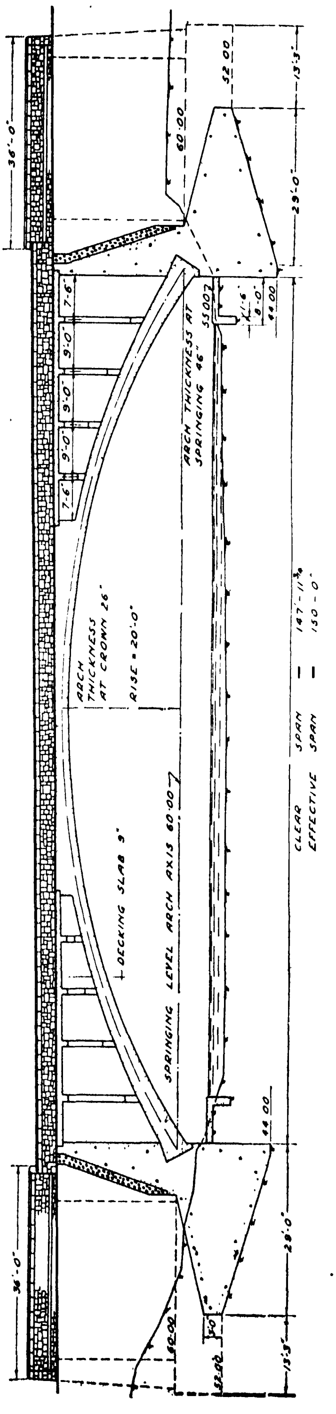


FIG. 122.—RIVER AWE BRIDGE: LONGITUDINAL SECTION.

150 ft. The rise is 20 ft. and the barrel is 2 ft. 2 in. thick at the crown and 3 ft. 10 in. thick at the springing.

The main reinforcement of the arch barrel is 1¼-in. bars at 8-in. centres at the crown, and 1¼-in. bars at 4-in. centres at the springing. Distribution steel throughout is ¾-in. bars at 12-in. centres. The wing walls are of mass concrete, approximately 32 ft. high, and are battered at 1 in 18 on the outside face and at 1 in 5 on the inside face. The abutments are of mass concrete, and are 29 ft. wide by 16 ft. deep and are mostly on rock. Between the spandrel walls and the junctions of the wing walls and abutments there are expansion joints.

The entire bridge, except the voussoirs and intrados of the arch ring, but including spandrel walls, wing walls, parapet walls, stringcourses, etc., is constructed of or faced with local stone masonry. The voussoirs are of pre-cast concrete units, with the exposed faces roughened as much as possible to resemble natural stone. This was necessary because of the difficulty in obtaining suitable stone.

The bridge provides for an 18-ft. carriageway and two 4-ft. 6-in. footpaths. The time taken in construction was about 18 months, and the cost was approximately £8,500. The contractors were Messrs. G. Wimpey & Co., Ltd.

NANT BRIDGE.

Spandrel-filled Arch of 50-ft. Span.

On the same road as Awe Bridge, and about two miles nearer Oban, Nant bridge is a parabolic spandrel-filled arch with a rise of 12 ft. 6 in. having a clear span of 48 ft. 7 in. and an effective span of 50 ft. A half longitudinal section and half elevation are shown in *Fig.* 124. The arch barrel is 12 in. thick at the crown and 21 in. thick at the springing. The main reinforcement is 1-in. bars at 12-in. centres at the crown and at 6-in. centres at the haunches. Between the layers of longitudinal bars are ½-in. distribution bars at 6-in. centres top and bottom. The total quantity of reinforcement is: 1-in. bars 23,559 lb.; ½-in. bars 5,169 lb.; ⅜-in. links 8,252 lb.

The abutments, wing walls, and spandrel walls are of mass concrete faced with local stone. The width of the abutments is 14 ft. and their depth is 11 ft. 6 in. below springing level on the river face and 2 ft.

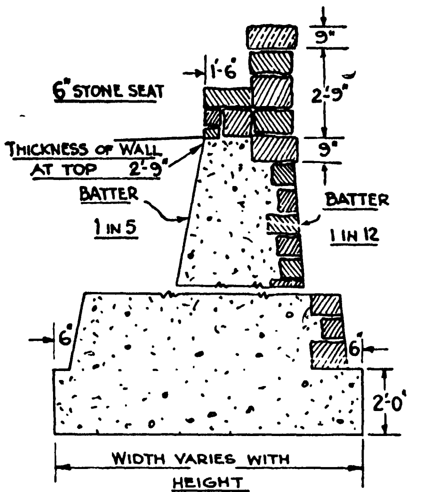


FIG. 123.—NANT BRIDGE: SECTION OF WING WALL.

at the back. The wing walls (*Fig.* 123) will be backed with 12 in. of hardcore, and 4-in. agricultural pipes will be inserted in the abutments for drainage. The parapets, cope and stringcourses are of rough-dressed local stone masonry. As at Awe bridge, stone suitable for voussoirs was unobtainable, consequently the arch barrel, after being increased in thickness at the face for æsthetic reasons, was left exposed and bush-hammered.

The bridge provides for an 18-ft. carriageway and two 4-ft. 6-in. footpaths, and the carriageway will be constructed on selected filling. Two coats of tar will be painted on the extrados of the vault and the backs of the spandrel walls.

The bridge is being erected on a 500-ft. radius curve, and has an angle of skew of 60 deg. (centre line of roadway to face of abutment). The carriageway will have a superelevation of 1 in. per foot of its width. Construction is still in progress, and the estimated cost is £2,216 13*s.* 8*d.* The contractors are Messrs. Geo. Wimpey & Co., Ltd.

STRONACHULLIN BRIDGE.

Slab-and-Beam Bridge on 50-deg. Skew.

This is an all-concrete structure, situated on the Arrochar–Campbeltown road (A83) about $3\frac{1}{2}$ miles south of Ardrishaig. The bridge (*Fig.* 125) is heavily skewed the angle of the face of the abutment to the centre line of the road being 50 deg. The skew span is 41 ft. Provision is made for

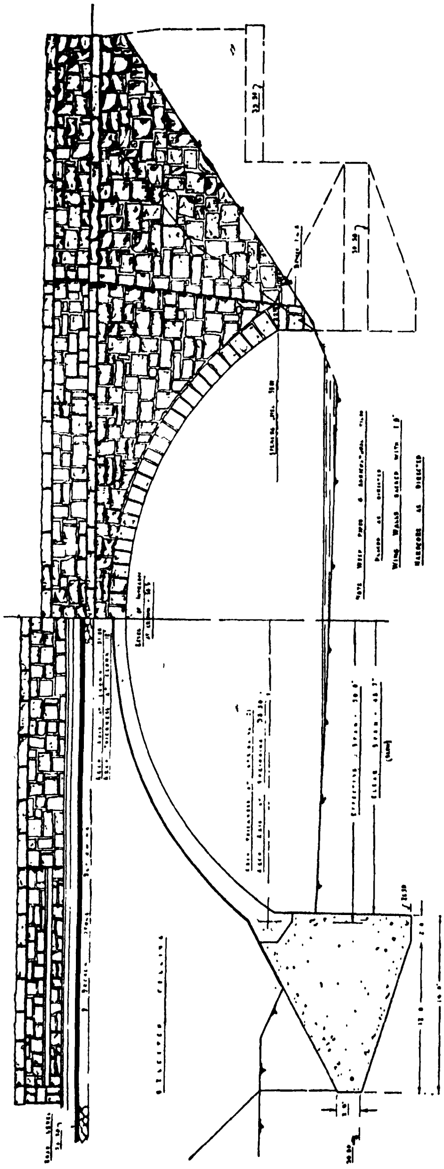


FIG 124.—NANT BRIDGE: HALF SECTION AND HALF ELEVATION.

a 16-ft. carriageway and two 5-ft. 6-in. footpaths.

Preliminary tests showed the ground to have a low bearing value, and the bridge was designed with reinforced concrete

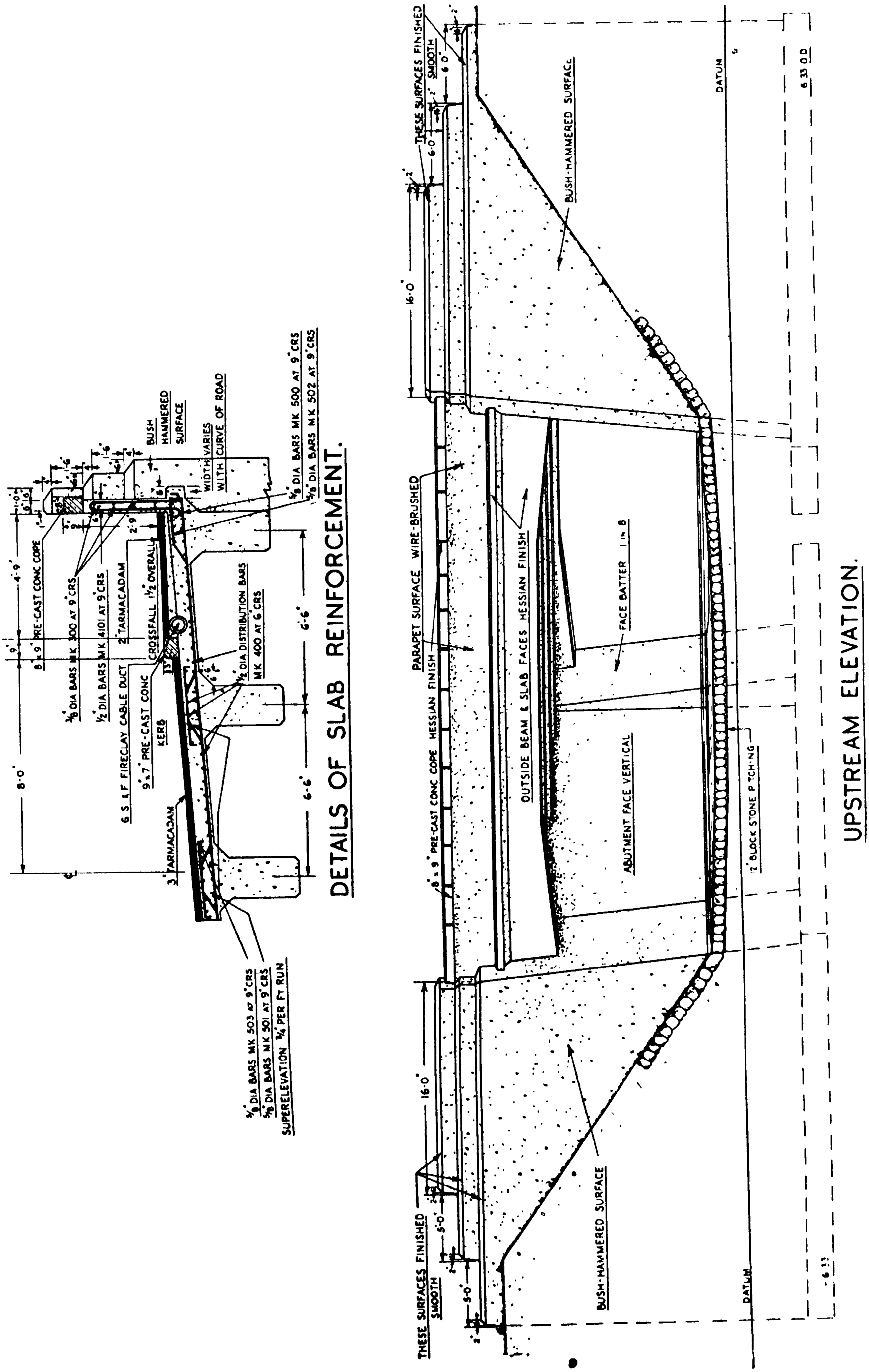


FIG. 125.—STRONACHULLIN BRIDGE.

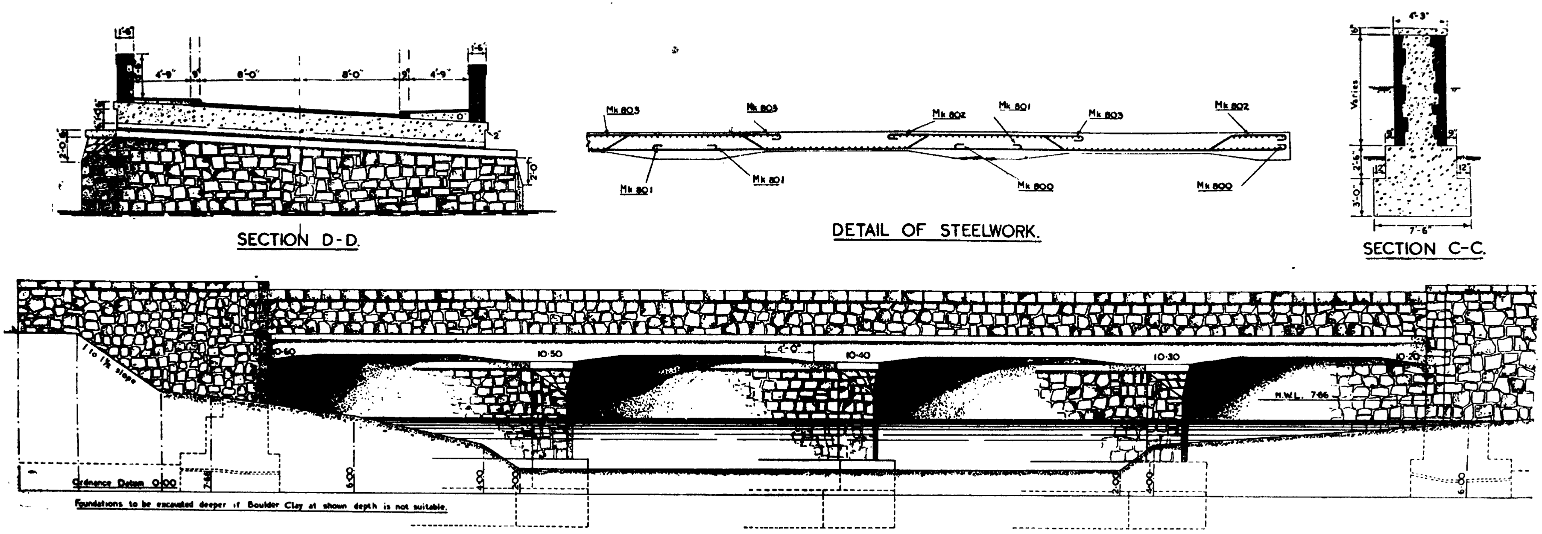


FIG. 126.—INVERNEILL BRIDGE: DOWNSTREAM ELEVATION.

counterfort abutments and a spread foundation, limiting the bearing pressure to approximately 2 tons per square foot. The abutment base slab is 14 ft. wide by 2 ft. thick, and was designed as a slab continuous over four spans. The counterforts—five in each abutment—are 1 ft. 6 in. wide and about 20 ft. high. The abutment wall slab, which is placed 6 ft. 6 in. from the outside toe of the abutment, is 9 in. thick at the top with a 1 in 18 face batter. The abutment foundations were carried almost 9 ft. below ground level.

The superstructure consists of a reinforced concrete deck slab continuous over five longitudinal beams, each beam being 19 in. wide by 36 in. (net) deep and the deck slab being 8 in. thick. Four of these beams are parallel to each other, but the fifth is offset slightly to accommodate a curve of the roadway which commences on the bridge. Details of the slab reinforcement are shown in the illustration.

The parapets over the span are of reinforced concrete 6 in. thick and carry a pre-cast concrete cope. The wing walls were designed as vertical cantilevers, and at the base are 2 ft. thick. The parapets, where over the wing walls, are of mass concrete, being continuations of the wing walls, without the steel, and decrease in 6-in. steps to a thickness of 12 in. No separate cope is laid, the parapet being so formed as to match the pre-cast cope over the span.

The surface finish of the wing wall faces is bush-hammered. On the outside beam and copes the surface is hessian finished, and on the thin sections of the parapet wire brushing is used. The bridge is still under construction and the contractors are Messrs. McKean & Co., Ltd., Glasgow. The estimated cost is £2,740.

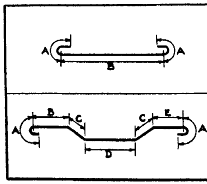
INVERNEILL BRIDGE.

Continuous Slab Bridge of four Spans.

Inverneill bridge (*Fig.* 126) is situated on a tidal site on the Arrochar–Campbeltown road (A83) about 3 miles south of Ardrishaig. It is of four-span continuous reinforced concrete slab construction, the spans each being 24 ft. on the skew, and is located on a curve of 720 ft. radius. The angle of skew of the abutment face to the tangent of the centre line is 50 deg. The bridge will carry a road 16 ft. wide and two 5-ft. 6-in. paths.

The abutments, piers, and wing walls are of mass concrete faced with local stone, and the abutments and piers are approximately 13 ft. high. The parapets, copes, and stringcourses are of local stone masonry.

The slab (*Fig.* 126) is 18 in. thick at mid-span and 24 in. thick at the supports, the main reinforcement being 1-in. bars at 5-in. centres with ⅝-in. bars at 6-in. centres as distribution steel throughout. The tops of the piers, which are 4 ft. 3 in. wide, will be screeded, and one layer of felt will be placed between the screeded surface and the underside of the slab.



MEMBER	QUANTITY	DIA OF BAR	LENGTH BEFORE BENDING	TYPE OF BEND	A	B	C	D	E	CWTS.	QRS.	LBS.
MK 800	72	1"	28'-2"	1	1'-2½"	25'-9"				48	1	10
MK 801	72	1"	30'-5"	1	1'-2½"	28'-0"				52	-	23
MK 802	72	1"	33'-11"	2	1'-2½"	12'-0"	2'-6"	10'-0"	4'-0"	58	-	24
MK 803	72	1"	41'-11"	2	1'-2½"	12'-0"	2'-6"	10'-0"	12'-0"	71	3	22
MK 500	190	⅝"	36'-0"	STRAIGHT						63	2	22

FIG. 127.—INVERNEILL BRIDGE: SCHEDULE OF SLAB STEEL.

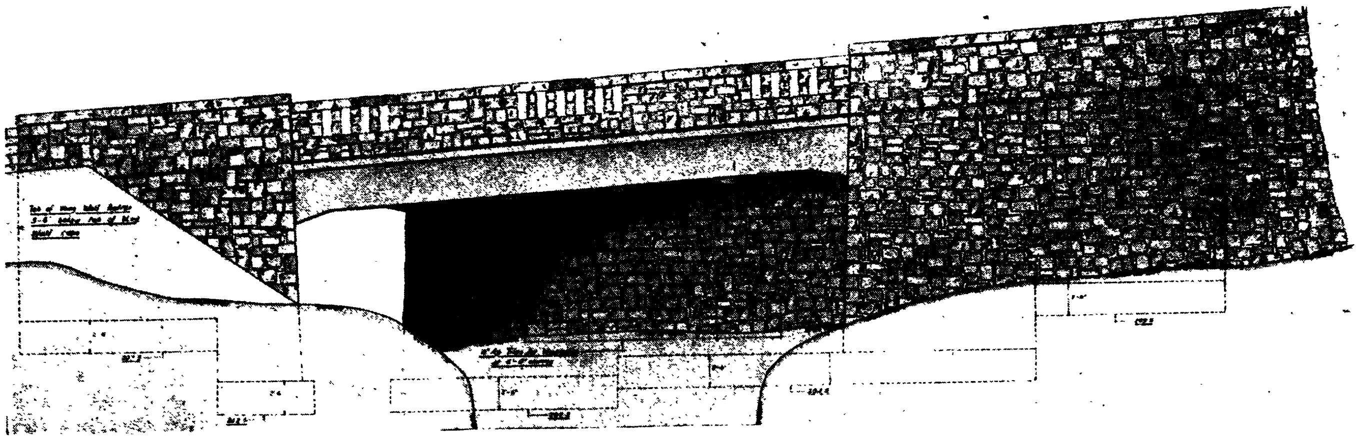


FIG. 128.—ELEVATION OF UPSTREAM SIDE.

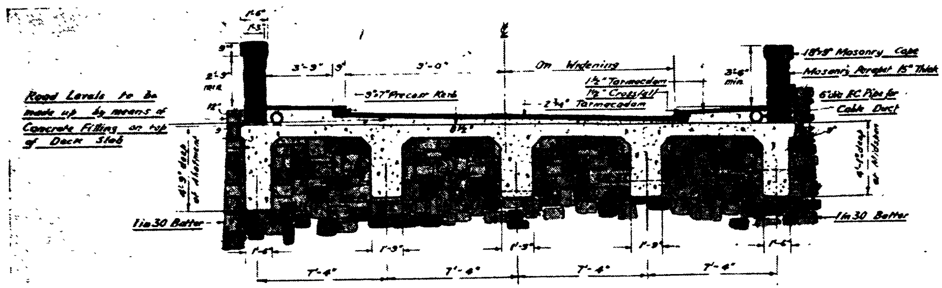


FIG. 129.—CROSS SECTION.

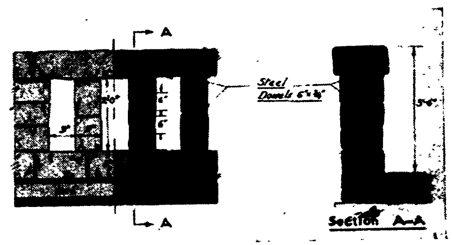


FIG. 130.—DETAILS OF PARAPETS AND DOWELLING.

CROE WATER BRIDGE (1ST CROSSING).

The total quantity of reinforcement in the slab, of which details are given in *Fig.* 127, is 293 cwt. The bridge is at present under construction, at an estimated cost of £3,075. The contractors are Messrs. McKean & Co.

CROE WATER BRIDGE (1ST CROSSING).

Longitudinal Beams on 1 in 15 Slope.

On the Arrochar–Campbeltown road (A83) about 3½ miles from Arrochar there is being built a 42-ft. skew span bridge of the deck and girder type. The angle of skew is 40 deg. The site is on a steeply sloping rocky mountainside, and the river at this point is practically a waterfall flowing through a deep gorge. The abutments are of mass concrete and are on rock, as are the wing walls. All are faced with local stone. An elevation of the upstream side of the bridge is shown in *Fig.* 128.

The superstructure consists of five longitudinal beams at 7-ft. 4-in. centres (see *Fig.* 129). The three roadway beams are 12 in. wide by 48 in. deep and the two parapet beams 18 in. wide by 48 in. deep. The deck slab is 9 in. thick and continuous over the five beams. The main reinforcement of the roadway beams consists of seventeen 1½-in. bars in two layers. Stirrups ½ in. in diameter are used throughout, the spacing varying to suit the conditions: The longitudinal beams are on a slope of 1 in 15.

The abutments and wing walls are of mass concrete faced with masonry, and are designed with footings 2 ft. 6 in. thick as shown in *Fig.* 128. The abutments and wing walls will be battered at 1 in 30 on the front face, and the top of the batter on the wing walls will be 5 ft. 6 in. below the coping. The hardcore behind the abutments will be drained to 4-in. agricultural tiles at 6-ft. centres passing through the abutments (*Fig.* 128). In the masonry parapets there will be openings 2 ft. high by 9 in. wide as illustrated in *Fig.* 130, with the stones connected by ¾-in. dowels 6 in. long. The bridge provides for an 18-in. carriageway and two 4-ft. 6-in. footpaths. The contractor is Mr. John McColville, Cardiff.

CROE WATER BRIDGE. (2ND CROSSING).

Two-span Slab Construction.

The second crossing of Croe Water is about quarter of a mile upstream from the first but on a very different site, the stream being shallow and the banks comparatively level. The bridge is of two-span continuous slab construction as shown in the longitudinal section (*Fig.* 131) along the centre line of the road. The spans are each 20 ft. in the clear and the angle of the skew is 53 deg. (abutment face to centre line of road). This bridge also

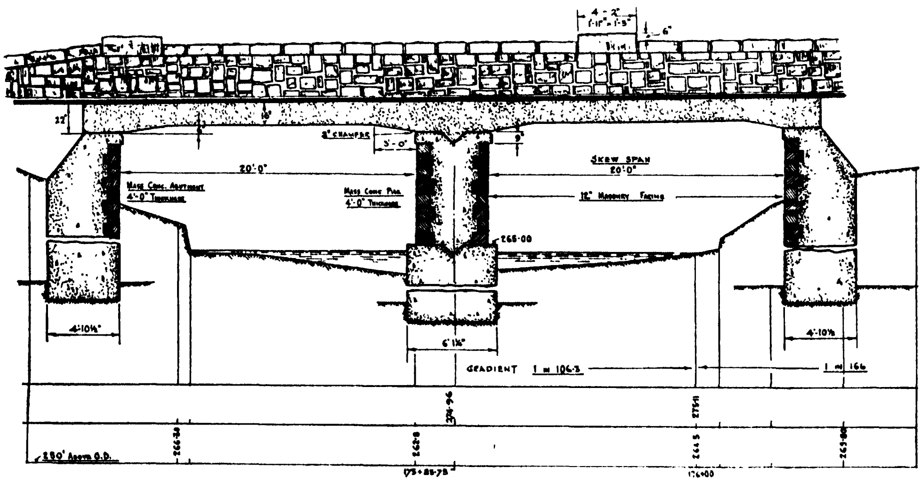
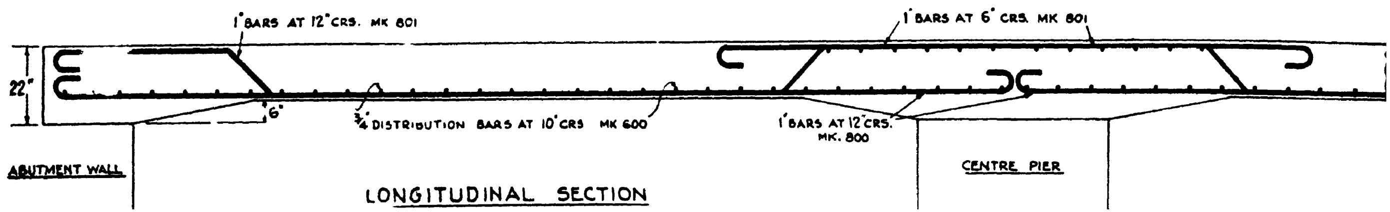
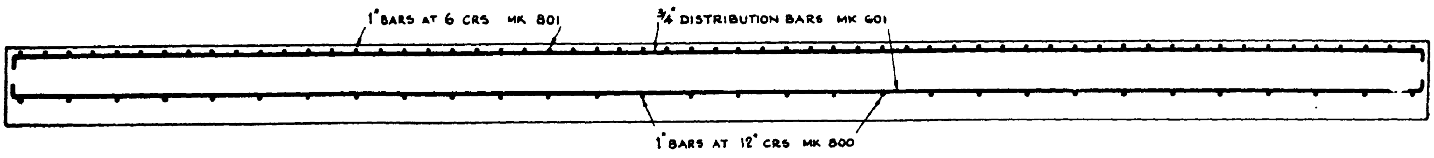


FIG. 131.—CROE WATER BRIDGE (2ND CROSSING): LONGITUDINAL SECTION ALONG CENTRE LINE OF ROAD.





NUMBER	QUANTITY	DIA OF BAR	LENGTH BEFORE BENDING	A	B	C	D	E	F	G	CONFIGURATION	CWTS
801	59	1"	34' 10"	5"	8"	4-3"	12"	1-6"	15-3"	12-2"		49
800	59	1"	26-2"	5"	8"	24'0"		·		·		36·8
600	72	3/4"	36'-3"	3"	35'9"	3"	·			·		35

FIG. 132.—CROE WATER BRIDGE (2ND CROSSING): DETAILS OF REINFORCEMENT IN SLAB.

provides for an 18-ft. carriageway and two 4-ft. 6-in. footpaths.

The slab is 16 in. thick at the crown and 22 in. thick at the supports, and the main reinforcement is 1-in. bars at 6-in. centres with ¾-in. bars at 10-in. centres as distribution steel. Sections through the slab are shown with the steel-bending schedule in *Fig.* 132.

The abutments, founded on rock, are of mass concrete faced with local stone, as are the wing walls and the central pier. The abutments and the central pier are approximately 13 ft. high and are 4 ft. thick, including the 12-in. masonry facings. A layer of hardcore in contact with the back of the wing walls, which are battered at 1 in 5, will provide drainage.

The parapets and coping are of local stone masonry, but the stringcourses are concrete cast in situ. The coping is 1 ft. 5 in. wide by 1 ft. 3 in. deep, and above the cutwaters there is a raised cap 4 ft. 2 in. long by 6 in. high as shown in elevation in *Fig.* 131. Construction has barely commenced. The estimated cost is £1,170, and the contractor is Mr. John McColville.

COBBLER BURN BRIDGE.

Construction of Piers on Side-Long Ground.

Forming part of the same contract as the Croe bridges, and on a diversion of the Arrochar Campbeltown road, the Cobbler Burn bridge (*Fig.* 133) stands on a steeply sloping mountainside and is over 500 ft. above sea level. It is of three-span viaduct construction, the spans being 37 ft. 6 in., 40 ft., and 37 ft. 6 in. between centres.

The superstructure (see *Figs.* 134 and 135) consists of fifteen longitudinal beams —five to each span—two transverse beams, and a deck slab. The transverse beams spanning across the tops of the piers are 5 ft. 4 in. deep below the slab and 2 ft. 6 in. wide; these are reinforced with twenty 1½-in. bars placed in two layers, and ten of the bars are cut or cranked at suitable points.

Details of the reinforcement are shown in *Fig.* 136. The longitudinal beams are at 6-ft. centres and 2 ft. 2 in. deep at midspan and haunched to 4 ft. 4 in. at the supports. The main reinforcement is eight 1½-in. bars placed in two layers. The stirrups are ½ in. in diameter throughout. At each side of the bridge the deck slab overhangs the outer beam for a distance of 3 ft. The slab is 8 in. thick and is reinforced with ⅝-in. bars at 4½-in. centres.

The abutments, which are comparatively low, are of mass concrete, faced with local stone masonry, and, in common with the piers, are founded on rock. There are four piers, 5 ft. by 5 ft. 6 in. in section and faced with masonry; they vary in height from 10 ft. to 30 ft.

The parapets are of local stone masonry, as are the copes and stringcourses.

Expansion joints, consisting of steel and copper plates where horizontal, and rubber and bituminous compound where vertical, are placed over each abutment, the piers being flexible to allow the entire superstructure to move.

The width of the bridge is 27 ft. between the parapets to carry an 18-ft. carriageway and two 4-ft. 6-in. footpaths. Construction has just commenced. The estimated cost is £2,360, and the contractor is Mr. John McColville.

BRIDGEND BRIDGE.

Skew-arch Construction.

This is an arch bridge on the Cairndow-Toward road (A815) about 16 miles north of Dunoon. Its span is 54 ft. 6 in. on the skew and 42 ft. 4 in. on the square. The bridge (*Fig.* 137) will carry a 16-ft. road and two footpaths, and the carriageway will have a superelevation of ⅞ in. per foot of its width.

The arch barrel (*Fig.* 138) is of 1 : 1½ : 3 reinforced concrete, with a rise of 7 ft. 6 in. The thickness at the crown is 1 ft. 3 in. and at the springing 2 ft. 4 in., the main reinforcement being ¾-in. bars at 6-in. centres and 1½-in. bars at 6-in. centres respectively. The distribution steel is ⅝-in. bars at 6-in. centres top and bottom. In all there will be about 17¾ tons of reinforcement in the arch.

The abutments, which are 15 ft. wide normal to the face, and the wing and spandrel walls are of 1 : 2½ : 5 mass concrete with masonry facing of local stone. The voussoirs, which are 1 ft. 6 in. deep at the crown and 2 ft. 4 in. deep at the springings, and cope are also to be constructed of this material. Construction has not yet commenced, and the estimated cost is £2,456.

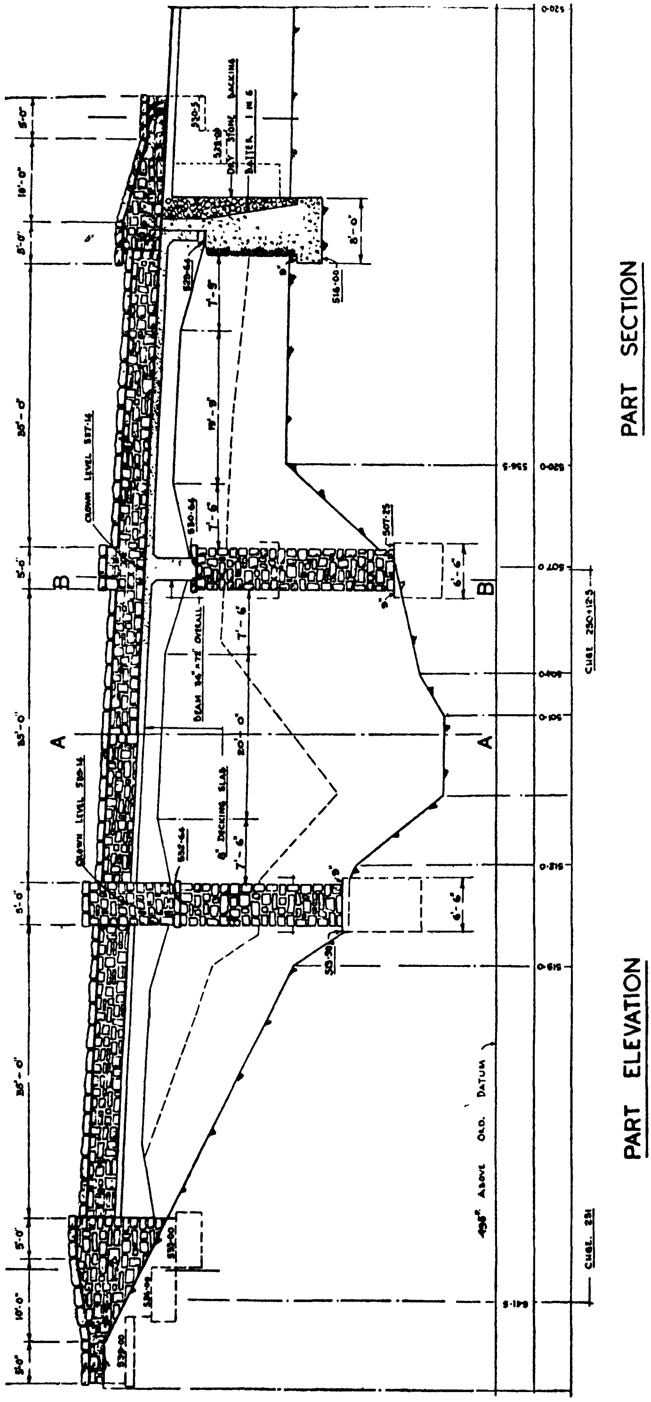


FIG. 133.—COBBLER BURN BRIDGE.

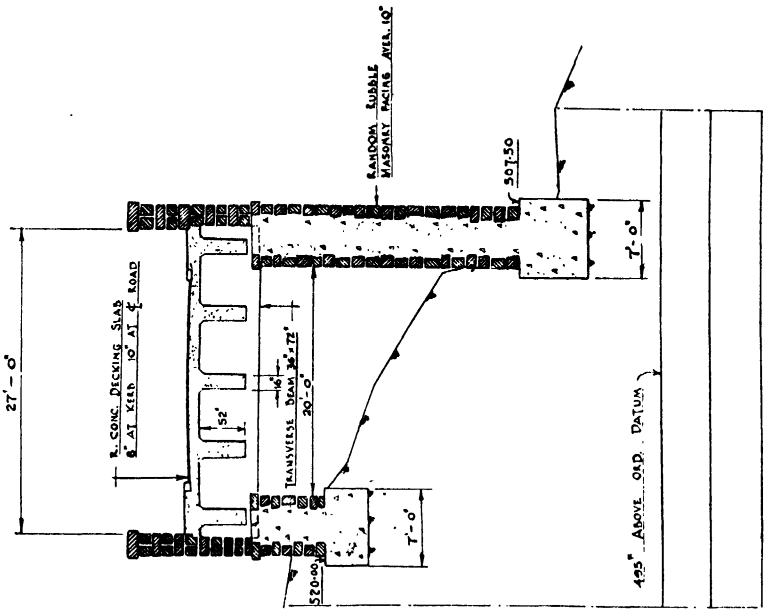


FIG. 135.—SECTION B—B AT SUPPORT.

COBBLER BURN BRIDGE.

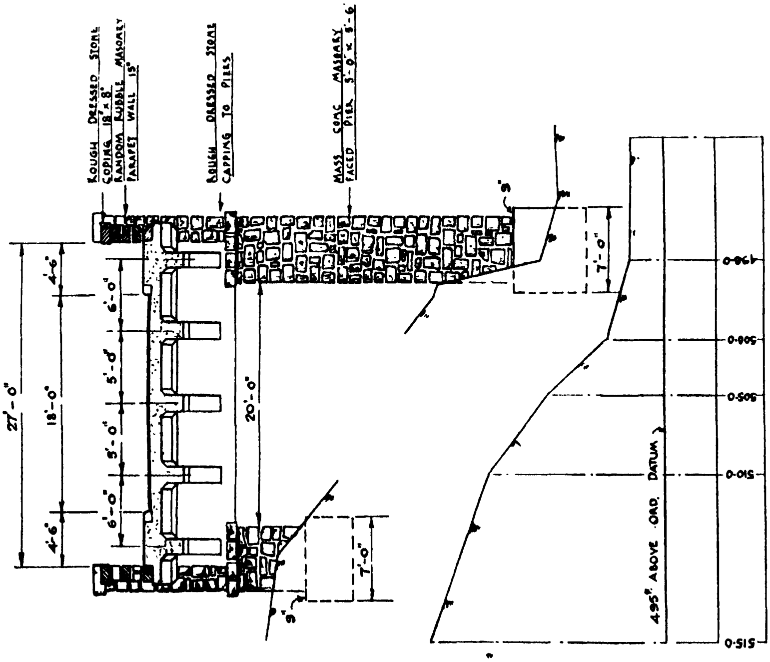


FIG. 134.—SECTION A—A AT MID-SPAN.

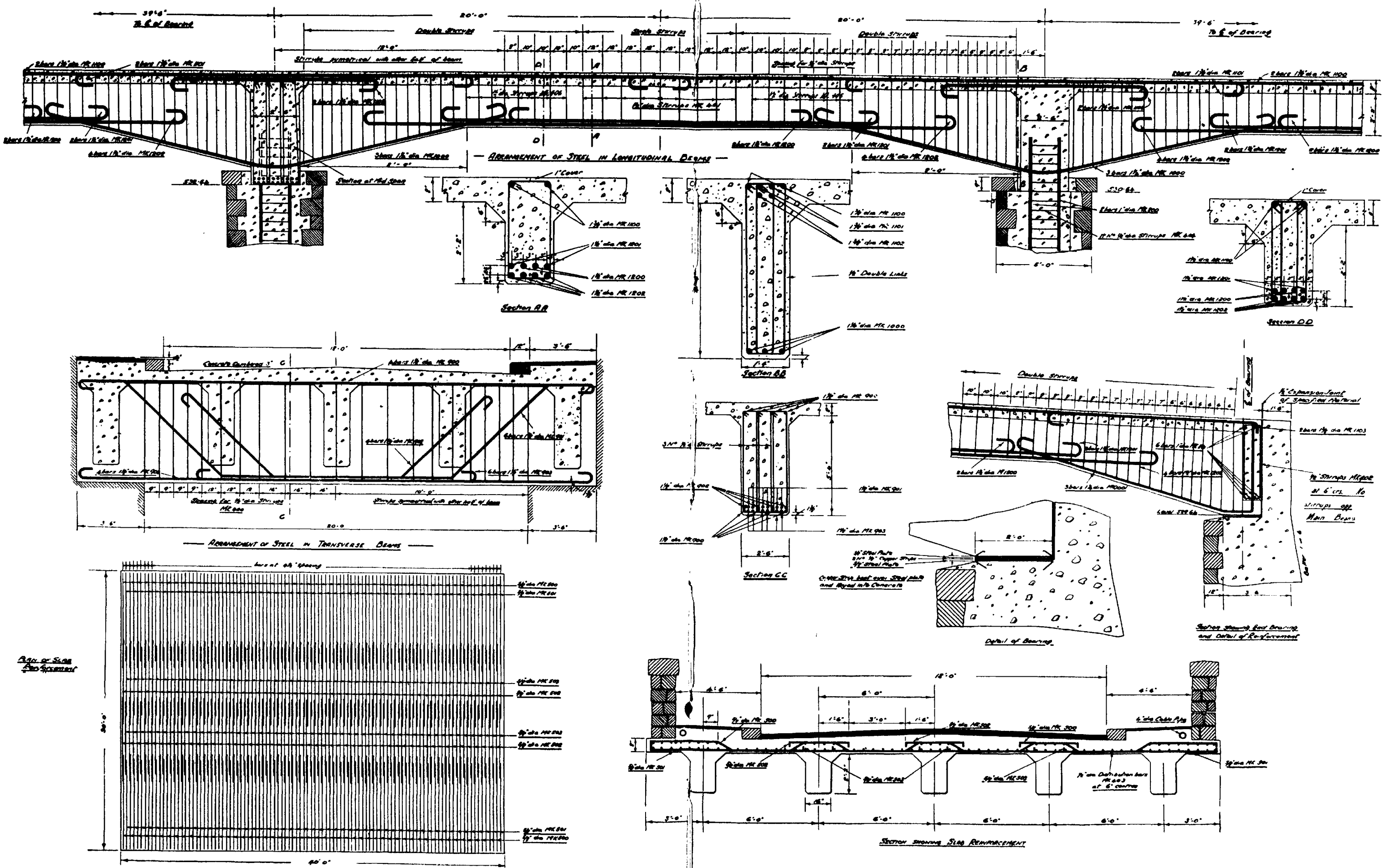


Fig. 136.—Cobbler Burn Bridge: Details of Reinforcement.

LAROCH BRIDGE.

Open-work Masonry Parapet Panels.

Laroch bridge (*Fig.* 139) is on the Carnoch–Connel road (A828) and is situated on an open site in Ballachulish village. It is of deck and girder construction with a skew span of 40 ft. and an angle of skew of 45 deg.

The deck slab is 9 in. thick and reinforced with $\frac{5}{8}$-in. bars at $4\frac{1}{2}$-in. centres with $\frac{1}{2}$-in. distribution bars at 9-in. centres; it is carried on five longitudinal girders 16 in. wide by 2 ft. 8 in. net depth, and placed at 6-ft. centres (*Fig.* 140). The main reinforcement of the girders consists of twelve $1\frac{1}{2}$-in. bars placed in three layers and $\frac{1}{2}$-in. stirrups are used throughout. The girder bearings consist of two $\frac{1}{8}$-in. copper plates; the ends of each copper plate are bent into the concrete above and below the steel plates.

The abutments are of mass concrete approximately 12 ft. high by 6 ft. wide, and are faced with local stone. The wing walls are of similar construction. The parapets are of local stone masonry, as is the cope, and will be constructed with open-work panels. Plastic filling will be inserted in the expansion joint over the abutment. The bridge provides for a 16-ft. carriageway with two 5-ft. 6-in. footpaths. Construction has recently commenced. The estimated cost is £1,500, and the contractors are Messrs. A. M. Carmichael, Ltd.

SALACHAN BRIDGE.

Spandrel-filled Skew Arch of 49 ft. Span.

This bridge is on the Carnoch–North Connel road (A828) about seven miles south of Ballachulish. It is a 49-ft. skew span spandrel-filled arch bridge with a rise of 9 ft. 6 in. The down-stream elevation shown in *Fig.* 141 is the original proposal, but has been amended by increasing the depth of the arch voussoirs by one-quarter and increasing the radius of the parapet so that the top of the coping is at the same level as the underside of the pylon coping. The new line of the coping is shown by a thin line above the slate stones. The illustration also shows the cross section at the crown and a half section at the springing.

The abutments are 14 ft. wide, and are

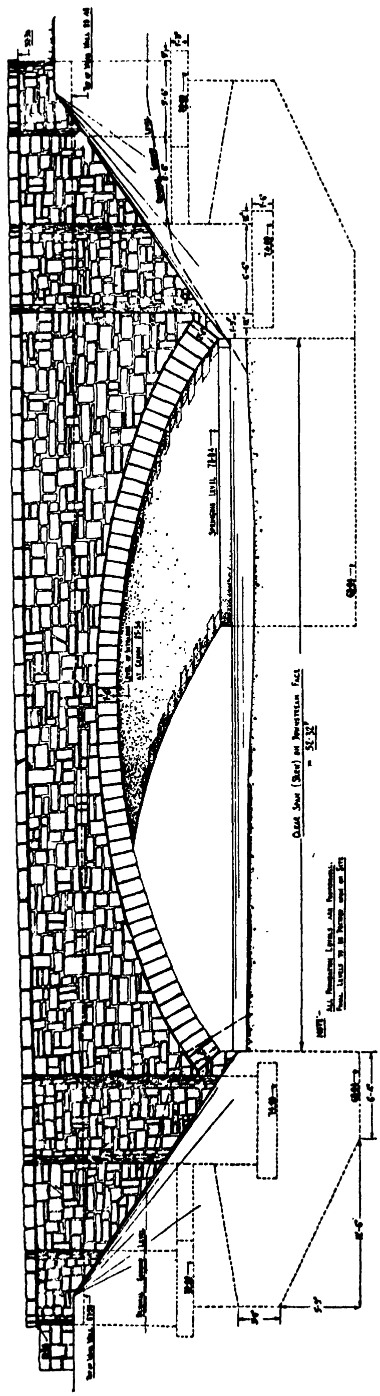


FIG. 137.—BRIDGEND BRIDGE: ELEVATION OF DOWNSTREAM SIDE.

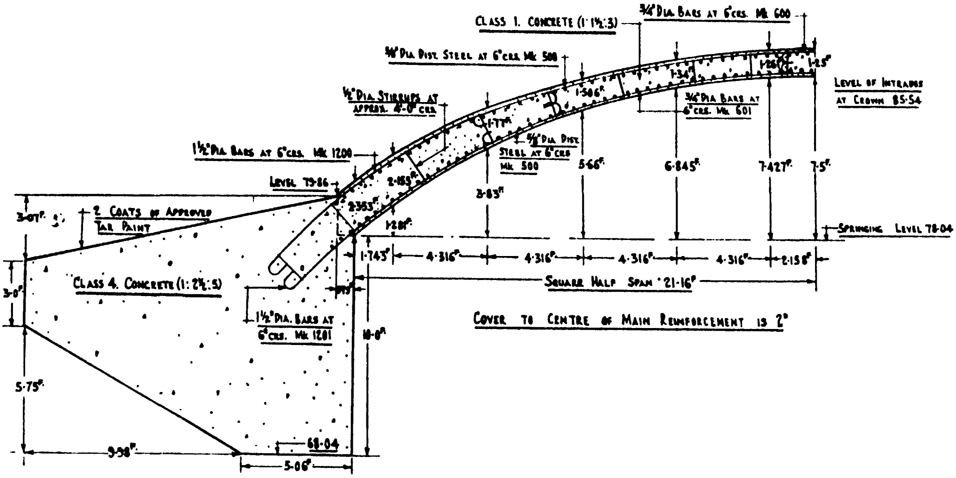


FIG. 138.—BRIDGEND BRIDGE: SQUARE HALF SECTION OF ARCH RING.

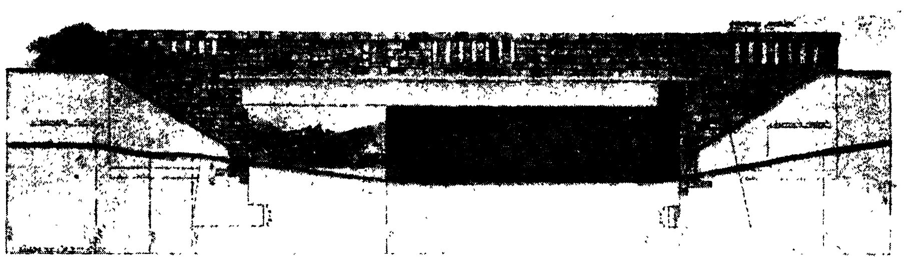


FIG. 139.—LAROCH BRIDGE: DOWNSTREAM ELEVATION.

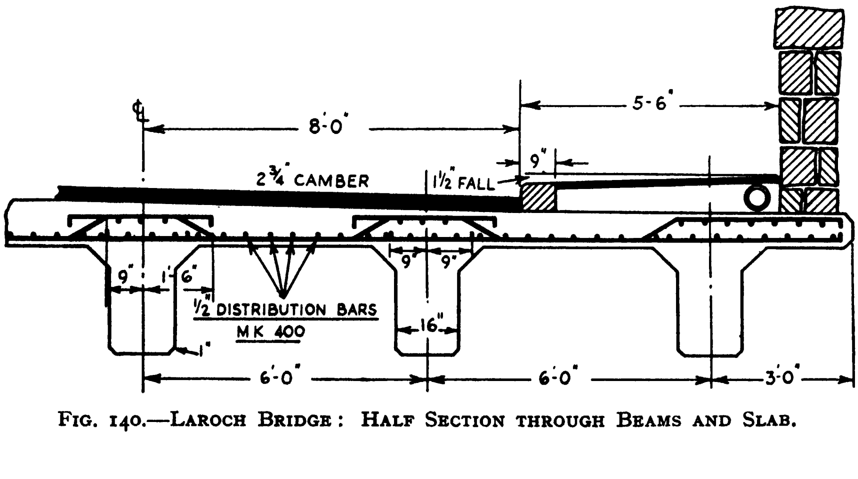


FIG. 140.—LAROCH BRIDGE: HALF SECTION THROUGH BEAMS AND SLAB.

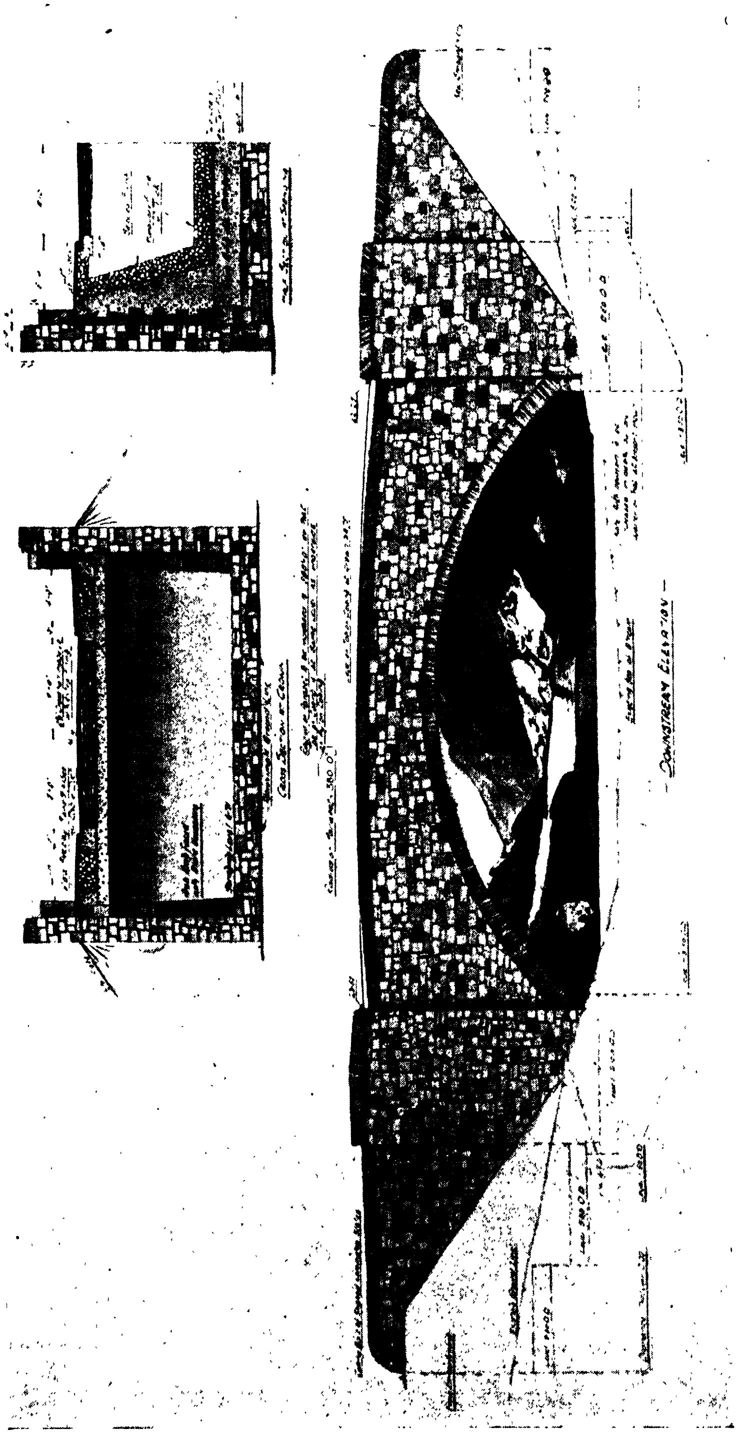


FIG. 141.—SALACHAN BRIDGE.

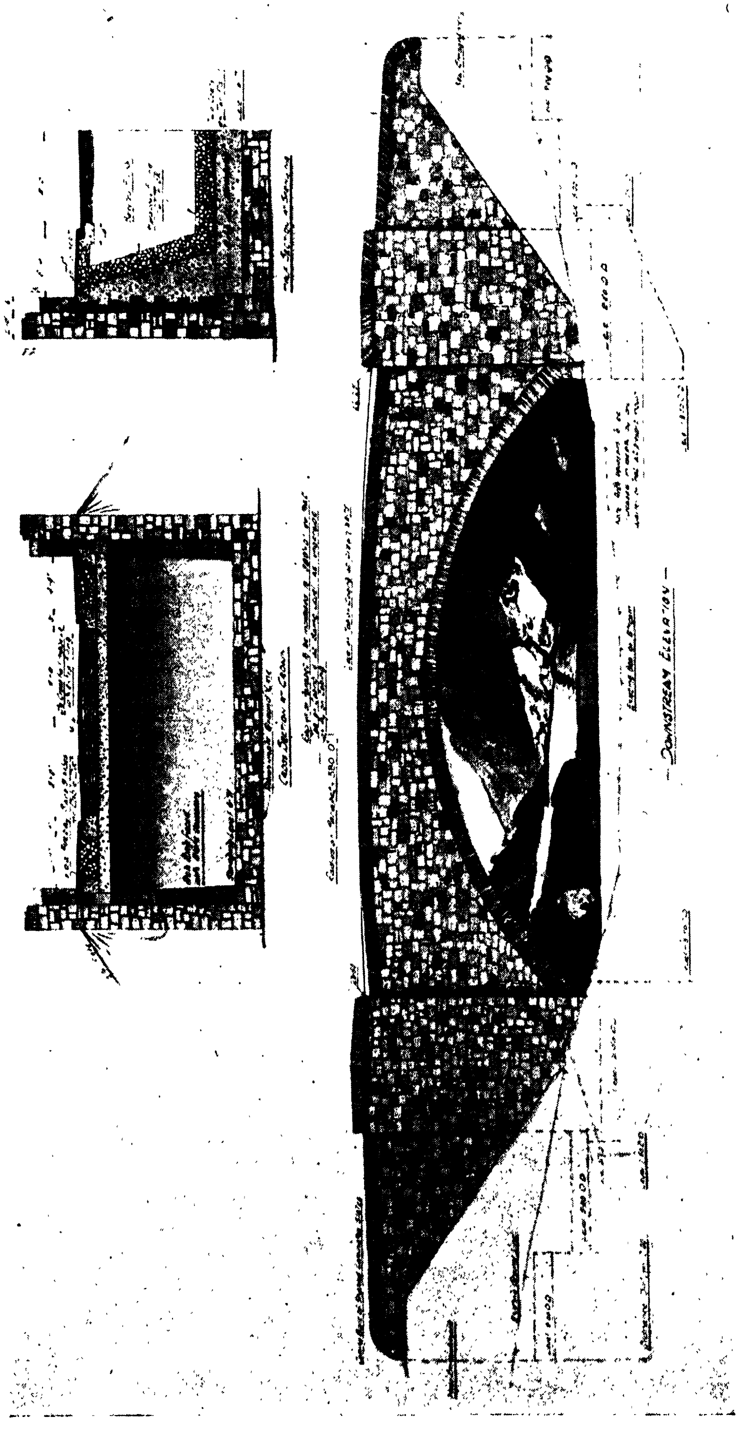


FIG. 141.—SALACHAN BRIDGE.

of mass concrete, as are the wing and spandrel walls, and all are faced with local stone masonry. The half section at the springing (see *Fig.* 141) shows 18 in. of hardcore filling laid on the arch ring (previously painted with two coats of tar paint) and covered with selected filling.

The reinforced concrete arch barrel is 12 in. thick at the crown and 18 in. thick at the springing, with 1-in. bars at 10-in. centres at the crown and 1⅛-in. bars at 5-in. centres at the springing. In addition to the longitudinal reinforcement, which amounts to 176 cwt. of 1⅛-in. bars and 53 cwt. of 1-in. bars, there are 57 cwt. of ⅝-in. distribution bars arranged at 6-in. centres in the top and bottom of the vault. The parapets are of local stone masonry, and the cope and voussoirs are formed of laminated slate-stone.

The bridge provides for a 16-ft. carriageway and two 5-ft. 6-in. footpaths. There is a 2⅛-in. cross fall in the carriageway made up with extra filling, and the extrados of the arch is to be covered with two coats of approved tar paint. Six-inch diameter fireclay socket-and-spigot pipes will be laid below the path on one side as a cable duct. Construction has just commenced. The estimated cost is £2,916, and the contractors are Messrs. A. M. Carmichael, Ltd.

ANCRUM BRIDGE, OVER THE RIVER TEVIOT

Three-span Filled-spandrel Arch.

ANCRUM BRIDGE carries the road from Edinburgh to Jedburgh and Hawick over the river Teviot on a skew of 60 deg. It is a three-span segmental arch bridge with earth-filled spandrels, and is 40 ft. wide between the parapets. The spans between the springings are 50 ft. 6 in., 58 ft., and 50 ft. 6 in., and the corresponding rises of the arch intrados are 13 ft. 5 in., 14 ft. 6 in., and 13 ft. 5 in. At the crown of the vaults the thicknesses are 13½ in. in the middle span and 12 in. in both side spans; at the springings the thicknesses of the vault are 20 in., 22 in., and 20 in. respectively. Immediately above the extrados of each arch there is a layer of insulation 1 in. thick covered with 9 in. of dry stone. The reinforced concrete cross walls are 10 in. thick, and the dry stone pitching is continued up their sides to provide drainage from the earth filling. Four-inch cast iron pipes laid through the bottom of the cross walls make the drainage system continuous from the arches to sumps above the piers and abutments from which 4-in. outlets are laid to the river.

The approaches are on vertical curves, but the roadway is level along the bridge and is composed of a carpet coat 1 in. thick laid on 3 in. of tarmacadam on 10 in. of bottoming laid with a 3-in. camber. The tarmacadam footpaths are 5 ft. wide.

The piers and abutments are of 1 : 2 : 4 mass concrete carried on 14-in. by 14-in. pre-cast reinforced concrete piles. Above the level of the river bed the piers and cutwaters are faced with ashlar masonry. The spandrel walls have a facing of random rubble masonry.

The consulting engineers for the bridge are Messrs. Blyth & Blyth, M.M.Inst.C.E., and the County Road Surveyor of Roxburghshire is Col. A. Forbes, M.Inst. M. & Cy. E. The contractors are Messrs. Rodger (Builders), Ltd., of Earlston. A perspective drawing of the bridge is reproduced in *Fig.* 142.

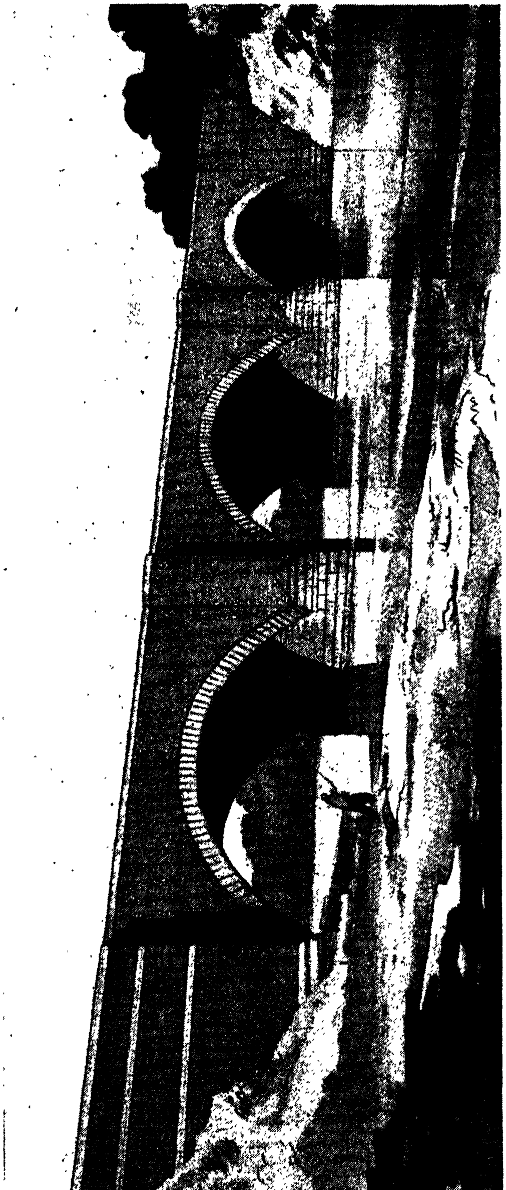


FIG. 142.—ANCRUM BRIDGE, OVER THE RIVER TEVIOT. (*See previous page.*)

Two bridges have recently been constructed in the North Riding of Yorkshire to the design of Mr. R. Sawtell, A.M.I.C.E., the County Surveyor.

Bense bridge is situated on the Tontine–Stokesley road (A172), where improvements are now being carried out providing a highway having an effective ultimate width of 80 ft. The net span of the bridge is 40 ft. It is designed to carry one carriageway, but the ultimate provision of twin carriageways has been anticipated. The foundations are enclosed in steel sheet piling of the Krupp type, and the abutments are reinforced with mild steel bars. The superstructure consists of compound 24-in. rolled steel joists encased in concrete which support a deck of reinforced concrete. The bridge was wholly constructed by direct labour.

Malton Gates bridge has been built in order to eliminate a level crossing on the A64 road. The net span of the bridge is 32 ft., which is in excess of the normal 26 ft. 6 in. required to accommodate two tracks. It is the normal practice of this authority to provide this increased span so as to prevent impact from the railway being transmitted to the cantilever toe of the abutments. There is also the advantage of added working space and the minimum of strapping and other works to the tracks when the abutment foundation work is in progress.

The abutments are of reinforced concrete 3 ft. thick. The superstructure is of compound 24-in. rolled steel joists, the bottom flanges of which are encased with concrete pre-cast prior to erection. The deck is of reinforced concrete.

The considerable skew of the bridge will be noted in the illustration. An unusual feature is that the girders are placed square to the abutments, involving the use of "flying" girders at the end which are supported on columns rising from the wing walls. A considerable saving in construction and also in steel has been effected by these means. The bridge was constructed by direct labour.

FIG. 143.—BENSE BRIDGE, NORTH RIDING.

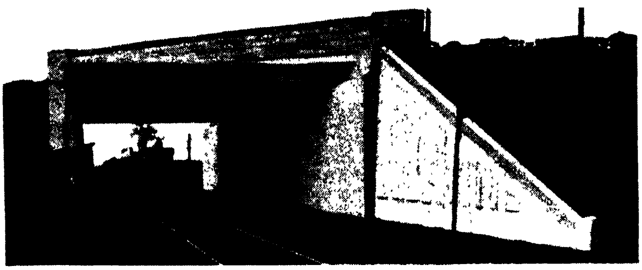


FIG. 144.—BRIDGE AT MALTON GATES, NORTH RIDING.

UPPER BOAT BRIDGE

The bridge over the river Taff at Upper Boat, which is being constructed by direct labour to the design of Mr. E. Charles Pole, County Surveyor of Glamorgan, comprises five spans carried on mass concrete abutments and piers supported on Pressure piles about 35 ft. long. Between parapets the bridge is 40 ft. wide, but the deck is splayed at one end to give easy access for traffic at a new roundabout. The bridge (*Figs.* 145 and 146) crosses the river on a skew of 80° 52′ 30″.

In designing the bridge the cantilever type was adopted. The distance between the face of the abutment and the centre line of the nearest pier at each end is 31 ft. and the distances between the centre lines of the interior piers are 34 ft., 36 ft., and 34 ft. Over the second and fourth spans the slab is continuous at both ends for a distance of 5 ft. 6 in. beyond the pier. One cantilever on each side carries the river end of the first and fifth spans, and the third, or middle, span of the bridge is simply supported at both ends on the 5-ft. 6-in. cantilevers which extend over its piers. In this way the thickness of the slab was kept low.

In the second and fourth spans, where the distances between the centre lines of the piers are 34 ft., the slab is 24 in. deep below the carriageway and is reinforced as follows: In the bottom to resist the positive moments there are $1\frac{3}{8}$-in. longitudinal bars at 6-in. centres under $\frac{7}{8}$-in. transverse bars at 12-in. centres. The longitudinal bars are 38 ft. long. In the top for lengths of 19 ft. inwards from the ends of the slab there are $1\frac{3}{8}$-in. longitudinal bars at 12-in. centres to resist negative moments and $\frac{7}{8}$-in. transverse bars at 12-in. centres. On each side of the bridge there is a pipe duct formed in the slab; this is carried on the outside by the parapet which is reinforced as a beam and is 12 in. thick. The piers are 23 ft. high by 2 ft. 6 in. thick and are carried on mass concrete foundations 51 ft. long by 8 ft. wide, each supported on twenty-six piles. Piles also support the abutments, which are 25 ft. 6 in. high and 12 ft. 6 in. wide at the bottom. With the exception of the row under the toe of each abutment, where the piles are battered at 1 in 8, all piles are vertical. There are thirty-five piles under the Tonteg abutment and fifty-six under the Upper Boat abutment.

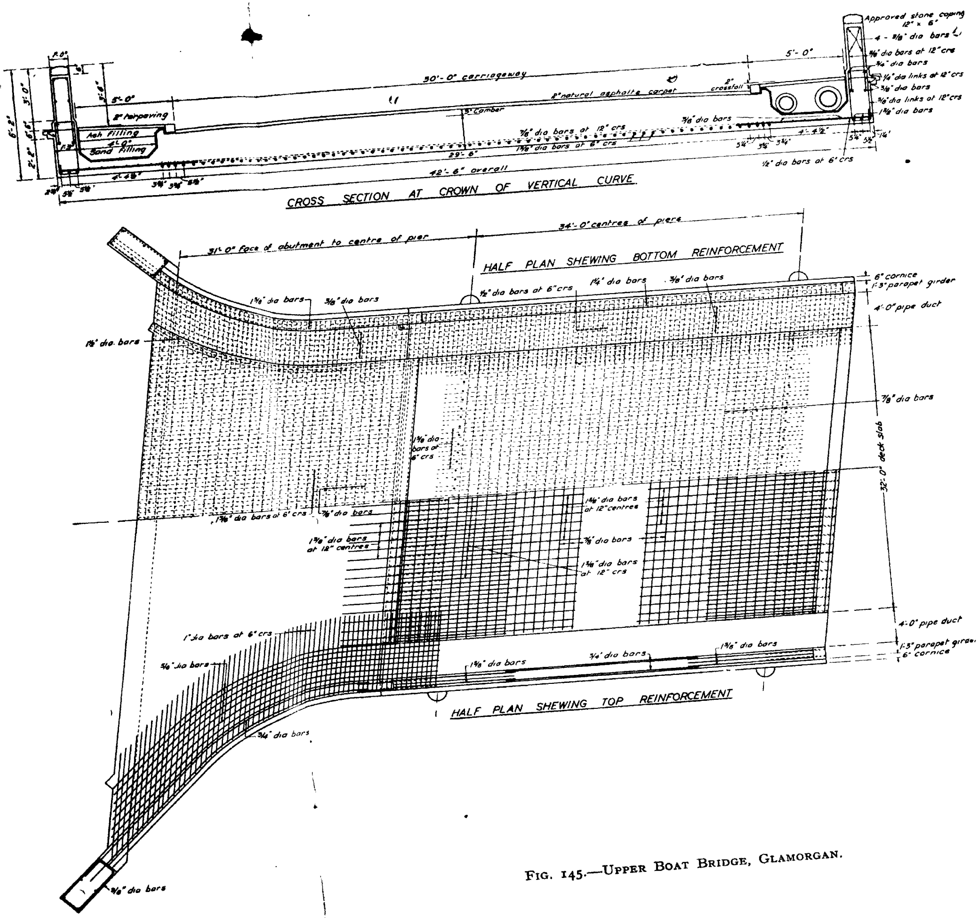


FIG. 145.—UPPER BOAT BRIDGE, GLAMORGAN.

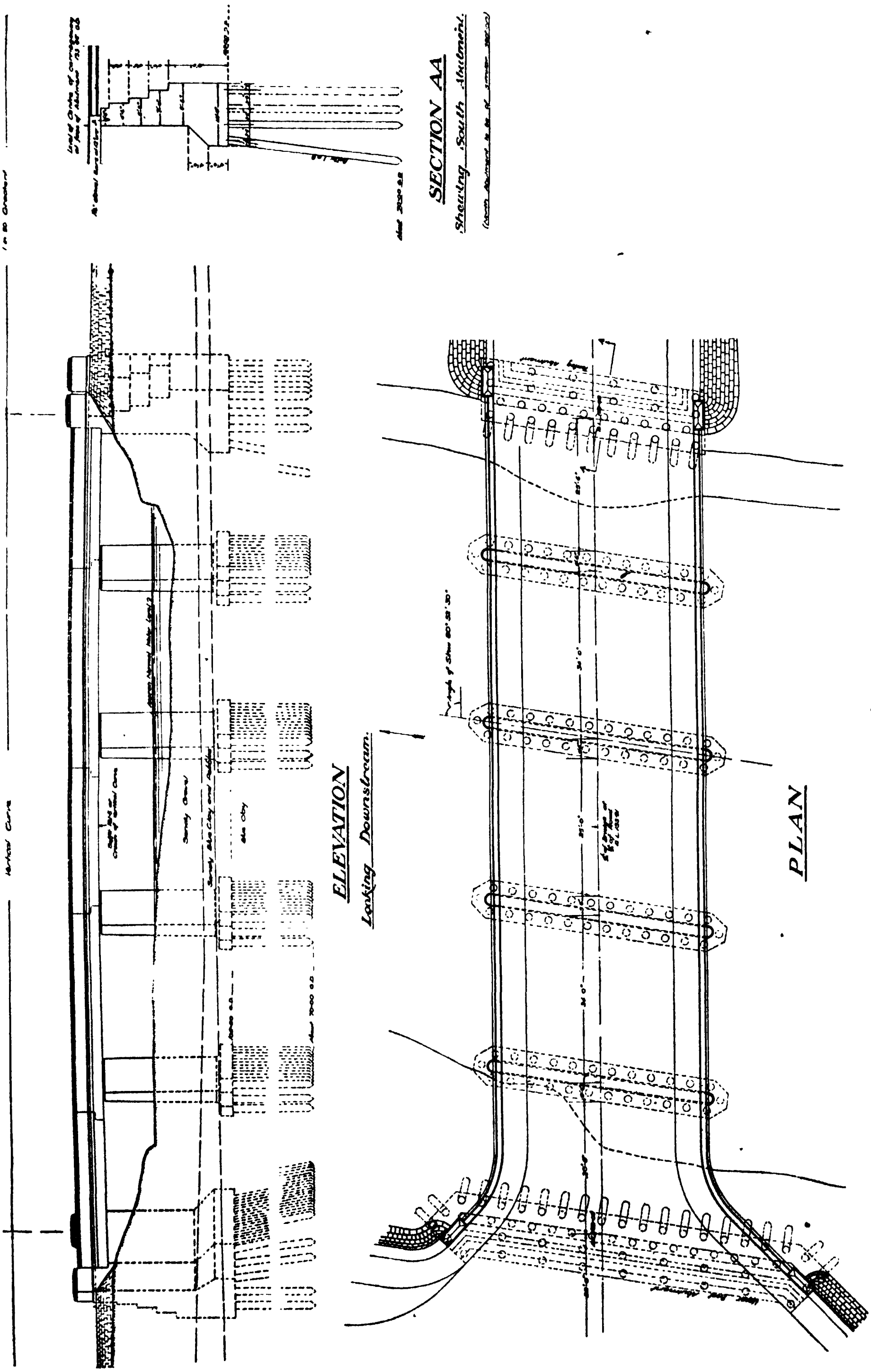


FIG. 146.—UPPER BOAT BRIDGE, GLAMORGAN. (See previous page.)

JOHNSTONE BRIDGE, DUMFRIES

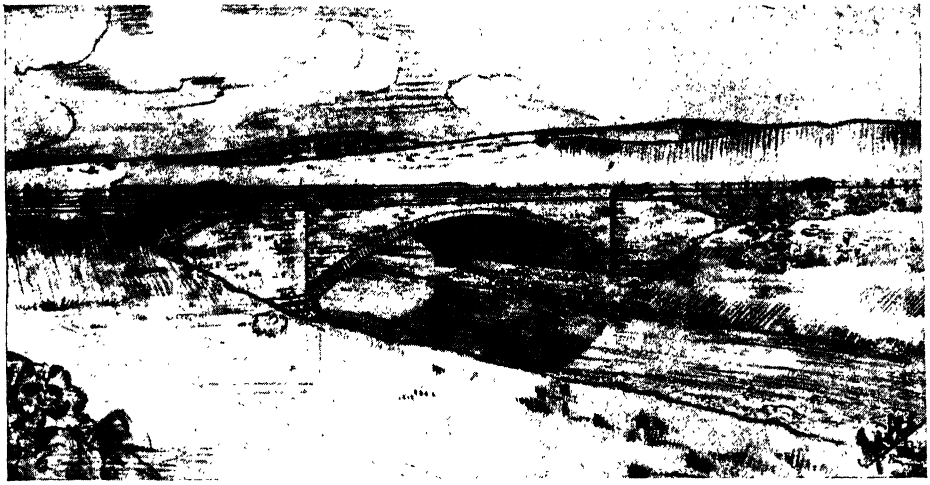


Fig. 147.

Johnstone Bridge, which is being erected by the Dumfries County Council for the Ministry of Transport's Trunk Road Scheme, in accordance with plans prepared by Messrs. Blyth & Blyth, M.M.Inst.C.E., is an earth-filled spandrel arch of 100 ft. span on a skew of 65 deg. It carries the Glasgow–Carlisle road over the river, and is 64 ft. between the parapets. This width accommodates two 22-ft. carriageways, separated by a 6-ft. grass strip, and two 7-ft. footpaths. The overall width of the bridge (*Fig.* 147) is 67 ft. 2 in.

The arch is segmental and the rise from springing level to the intrados at the crown is 20 ft. At the crown the thickness of the arch vault is 2 ft., increasing to 4 ft. at the springing. Road level at the middle of the span is 2 ft. above the extrados of the arch. There are eight reinforced concrete cross walls faced with 9 in. of dry stone for drainage. Between the walls there is selected dry filling laid on dry stone above the extrados of the arch and carrying the 10-in. bottoming of the tarmacadam carriageway.

In the arch the concrete is a 1 : 1½ : 3 mix, and in the abutments the mass concrete is in the proportions of 1 : 2 : 4. The voussoirs are dressed ashlar and the spandrel walls and wing walls are faced with freestone. The parapets and piers at the ends are dressed ashlar.

The County Road Surveyor is Mr. Albert V. Hart and the contractors are Messrs. W. & J. R. Watson, Ltd., of Edinburgh.

TIENDSIDE BRIDGE, OVER THE RIVER TEVIOT

About half-way between Hawick and Teviothead the Carlisle–Hawick road crosses the river Teviot on a reinforced concrete arch bridge having a span of 116 ft. on a skew of 45 deg. The carriageway is 21 ft. wide and there are also two 4-ft. 6-in. paths, making a total width of 30 ft. between the parapets.

Pylons spaced 133 ft. 6 in. apart are a noteworthy feature of the elevations. The wing walls are mass concrete walls, and at the Hawick end one wall is curved where a secondary road is retained. The spandrel walls and the pylons have concrete surfaces, but the parapets have been faced with buff-coloured " Cullamix " with a scraped finish and synthetic freestone with a natural freestone cope all matching in colour.

The bridge (see *Fig.* 148) was constructed for the Roxburgh County Council by Messrs. A. A. Stuart & Sons, Ltd., of Glasgow. The consulting engineers were Messrs. Blyth & Blyth, M.M.Inst.C.E., collaborating with Col. A. Forbes, M.Inst. M. & Cy. E., County Road Surveyor.

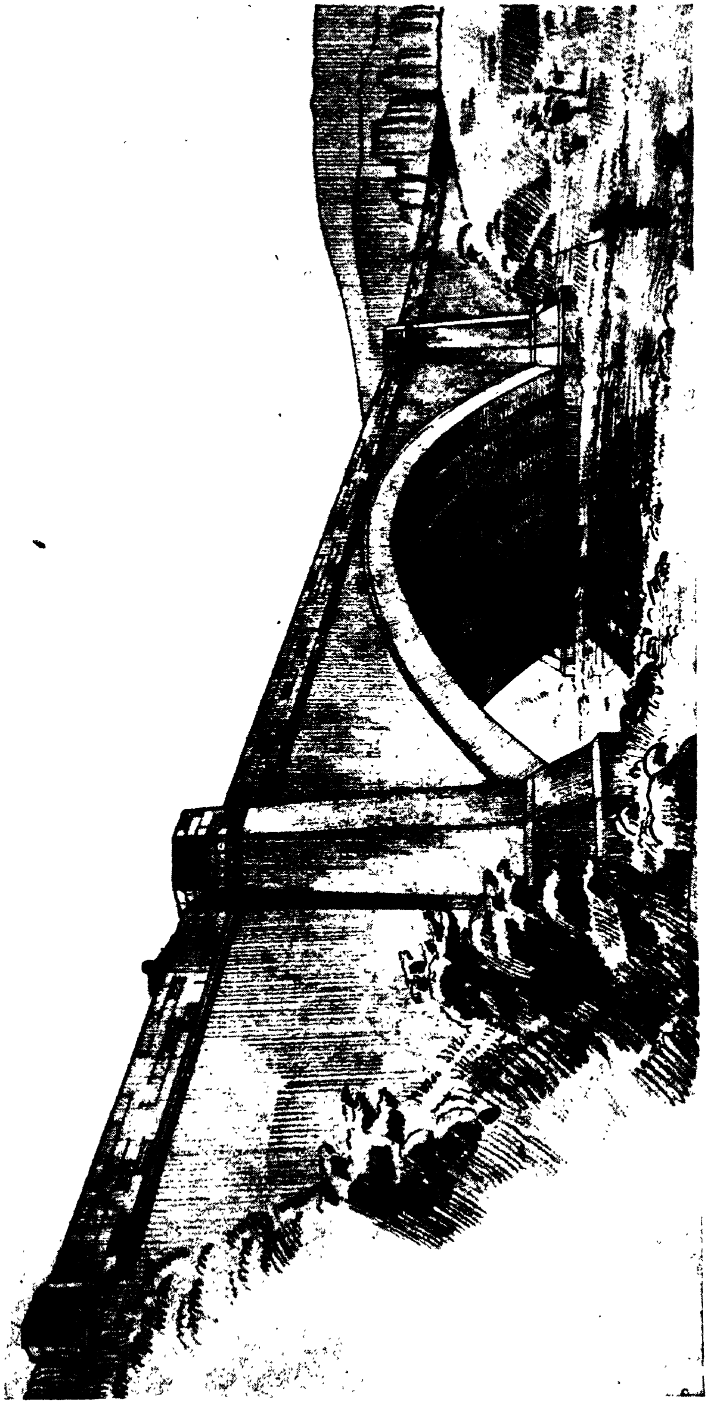


FIG. 148.—TIENDSIDE BRIDGE, OVER THE RIVER TEVIOT. (*See previous page.*)

WILFORD BRIDGE, MELTON, EAST SUFFOLK

Skew Span of 76 ft.

THE existing bridge over the river Deben consists of two brick arches each of 25-ft. span and 10-ft. 6-in. rise; the abutments and a pier in mid-stream are constructed in brickwork. No information is available regarding the date when the existing bridge was constructed, but the central pier was repaired by fitting cast iron fascias in 1830. The width between parapets is 13 ft. Owing to the bad alignment of the bridge, its humped nature and the restricted width, the bridge has become unsuitable for modern traffic. The County Council therefore decided that a new bridge should be constructed.

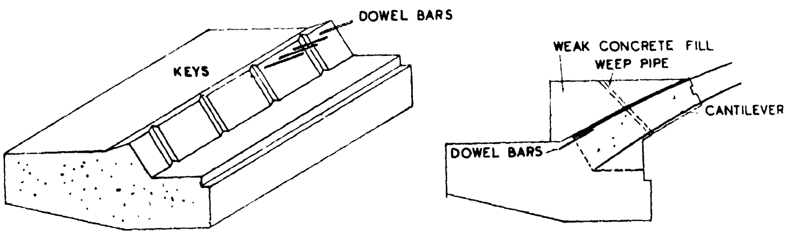


FIG. 149.

Design of the New Bridge.

The new bridge (*Figs.* 150, 151 and 152) is a reinforced concrete arch with a 76-ft. skew span, a rise of 11 ft., and an angle of skew of 43 deg. The thickness at the crown is 19 in. and at the springing 35 in. The main reinforcement will be spaced at 5-in. centres throughout, the diameters of the bars being as follows: At the springing $1\frac{1}{2}$ in., at the haunches $1\frac{1}{8}$ in., at the crown $\frac{3}{4}$ in. with an increase to $1\frac{1}{8}$ in. at the crown for the first 6 ft. inwards from the parapets. The nominal mix of concrete is to be 90 lb. : 1·5 cu. ft. : 3 cu. ft. for the arch and 90 lb. : 2 cu. ft. : 4 cu. ft. for the abutments. The width between parapets will be 40 ft., which allows for a 20-ft. carriageway, two footpaths of 5 ft., and two grass verges of 5 ft. The verges may be used later for widening the carriageway to 30 ft. The new road will have a uniform gradient of 1 in $53\frac{1}{2}$ over the bridge and approaches.

The foundations of the west abutment have been constructed on reinforced concrete piles with an average penetration of 20 ft., a 30-cwt. drop hammer with a drop of 3 ft. being used. The final set was $\frac{1}{4}$ in. to ten blows. A test was made by applying a hydraulic jack to a selected pile, the reaction being supplied by a stiff steel girder anchored to two piles on either side. A load of 70 tons was applied, the settlement being $\frac{1}{8}$ in. with complete recovery after removal of the load. A short portion of the arch on the west side was constructed as a cantilever (*Fig.* 149). The same procedure will be followed on the east side, and the middle 62 ft. of the arch will be constructed in three sections. As will be seen from the plan (*Fig.* 153, F) part of the new east abutments overlaps that of the existing bridge. It is therefore impossible to complete the new work until the old bridge is demolished. A half-width of the new arch will first be constructed (*Fig.* 153, G) and then, in order to avoid undue vibration in this work, "Bored" piles will be used for the north-east part of the east abutment. Particular care is being taken to preserve local amenities. The elevation of the bridge and parapet walls are being constructed in "autumn tint" bricks, the quoins and coping in reconstructed stone, and the face of the arch is being finished in reconstructed stone cast in situ to match the quoins. The brick facing to the mass concrete retaining walls is $4\frac{1}{2}$ in. thick, being bonded in by headers. No particular difficulty has been found in this, mainly because only about five courses of bricks have been laid previous to backing up with concrete.

Special Points of Interest.

Due to the cantilever method of construction which has been used for the

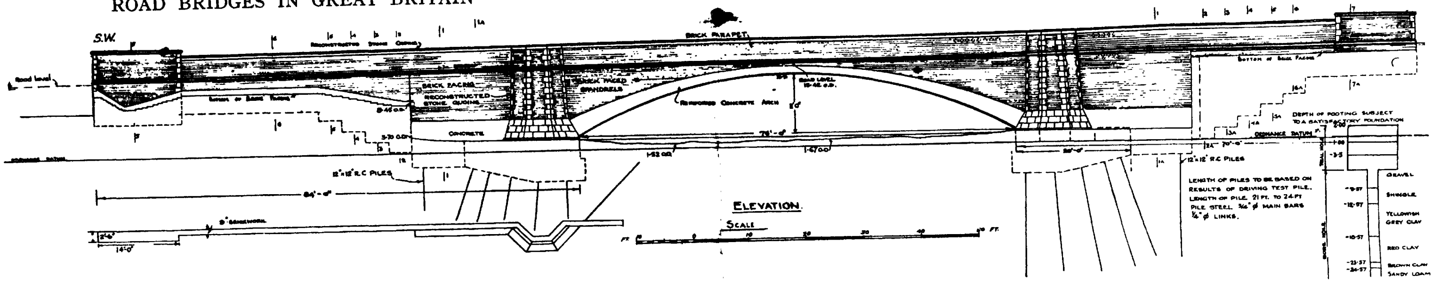


FIG. 150.

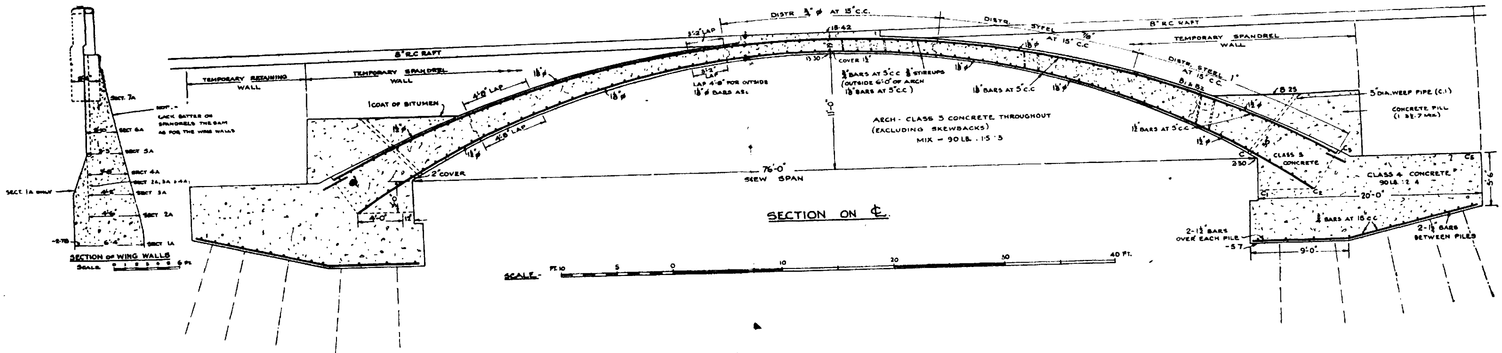


FIG. 151.

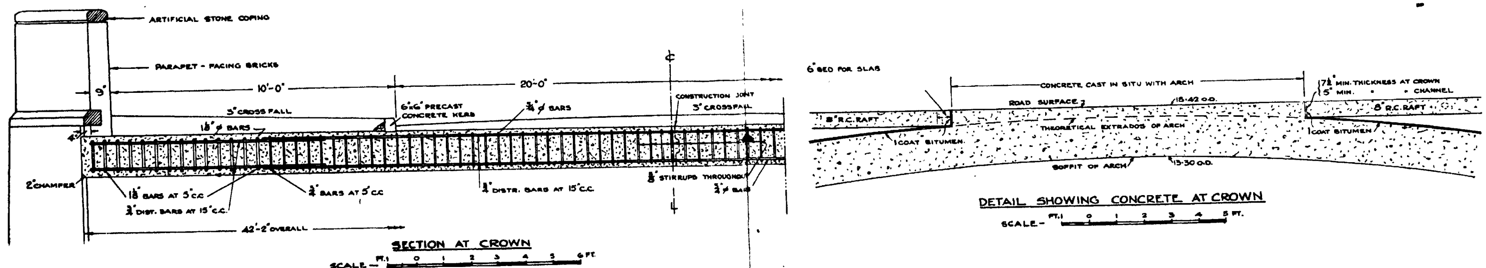


FIG. 152.

WILFORD BRIDGE, MELTON, EAST SUFFOLK.

springings of the arches it was necessary to tie the skewback to the abutment with dowel bars as shown in *Fig.* 149. With a view to avoiding sliding along the skewback, a tendency to which is caused by the thrust parallel to and along the skewback by the "skew" effect of the arch, keys have been introduced in the skewback. In order to avoid softening the filling over the abutments by the tides rising up the weep pipes, a block of weak concrete filling is introduced over the abutments.

The pilasters are primarily an architectural feature, but their bases give the necessary extra strength to the foundations of the arch at a weak point in skew designs. Concrete piles have been placed under this work as under the remainder of the abutment.

The approach road will be of concrete 8 in. thick, reinforced top and bottom with ¼-in. diameter bars at 6-in. centres both ways. The 6-in. by 6-in. kerbing will be of pre-cast concrete laid near the edge of the concrete raft and backed with 6 in. of concrete.

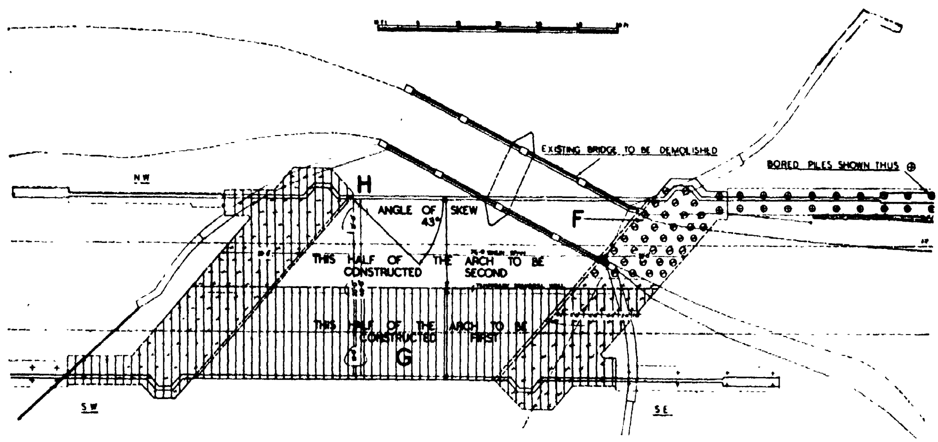


FIG. 153.

The reinforcement in the arch at the crown is doubled immediately under the spandrel walls and for 6 ft. in from each face. This is to give greater strength on the weakest portion of the "skew" arch. Instead of an abrupt change from the heavy reinforcement calculated as necessary at the springing (4·24 sq. in. per foot) to lighter reinforcement at the crown (1·06 sq. in. per foot) an intermediate amount of reinforcement (2·39 sq. in. per foot) is used in the haunches. The distributing bars are rather heavier than would be usual in a square arch, being 1-in. bars at the springing, ⅞-in. at the haunch and ¾-in. at the crown, all at 15-in. centres.

The total estimated cost of the work is £15,000, of which £12,378 represents bridgework, the remainder being the cost of approach roads and other items. As the area of waterway covered by the arch is 3,200 sq. ft. the approximate estimated cost of the bridgework alone is £3·87 per square foot of area spanned.

The contractors are Messrs. Currall, Lewis & Martin, Ltd. The engineer is Mr. J. B. Lund, A.M.Inst.C.E., M.I.Struct.E., A.M.T.P.I., County Surveyor of East Suffolk, by whose permission these notes have been prepared by Mr. E. A. Mobberley, B.Sc., A.M.Inst.C.E.

BRIDGE OVER RIVER ORCHY, ARGYLL

Beam-and-Slab River Spans of 83 ft. and 70 ft.

WORK is in progress on the construction of a new bridge over the river Orchy, between Dalmally and Lochawe, Argyll. The bridge will form an important link on trunk road A85 (Tyndrum–Oban road) and shorten the distance to Oban by slightly over one mile from the east and over three from the south.

Proposals for the construction of a bridge were first drafted in 1931 and a contract to the value of £27,000 was on the point of being accepted when national emergency measures caused its abandonment. Consideration of the scheme was resumed in 1933, when a different design on a new site was prepared at an estimated cost of £20,000. This latter scheme, however, met with adverse criticism from the Society for the Preservation of Rural Scotland and the Royal Fine Arts Commission, and it too was eventually abandoned. Pending adjustment, the bridge approach embankments and other adjacent road works were let by contract and were completed, with the exception of the surfacing of the carriageway.

By 1937 a scheme meeting with the approval of the Royal Fine Arts Commission had been prepared, and the works were let by contract at an estimated cost of £40,000.

Details of the Design.

The arrangement of the bridge now under construction consists of a three-span main river crossing with five flood arch approaches and a small-span cattle creep. The approach arches are spandrel-filled segmental arches, each of 50 ft. clear span, the arches being 13 in. thick at the crown, 20½ in. thick at the springings, and reinforced with 1¼-in. diameter bars at 5¾-in. centres, lapped about 4 ft. at the crown and springing. The spandrel walls are of reinforced concrete cantilevering from the arch barrel in the usual way. The abutments and piers are of mass concrete, the former carrying cantilever head walls, and the foundations of the latter being made eccentric to compensate for the reactions of the unbalanced dead load due to the 1 in 50 rising road gradient.

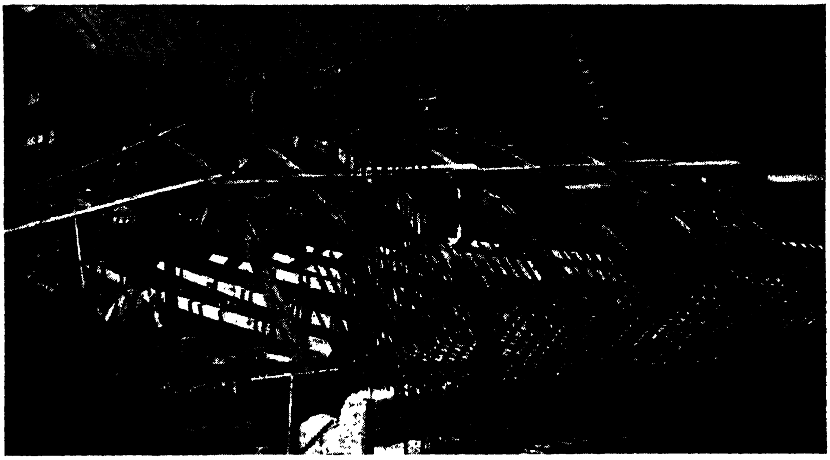


FIG. 154.—BRIDGE UNDER CONSTRUCTION.

The main river crossing (*Fig.* 155) consists of a three-span beam-and-slab arrangement with clear spans of 70 ft., 83 ft., and 70 ft., the elevation having the appearance of three flat arches of equal rise-span ratio. There are four main beams in each span. The side spans are fixed at the abutments and cantilever over the river piers to form the centre span which is completed by a 40-ft. suspended section.

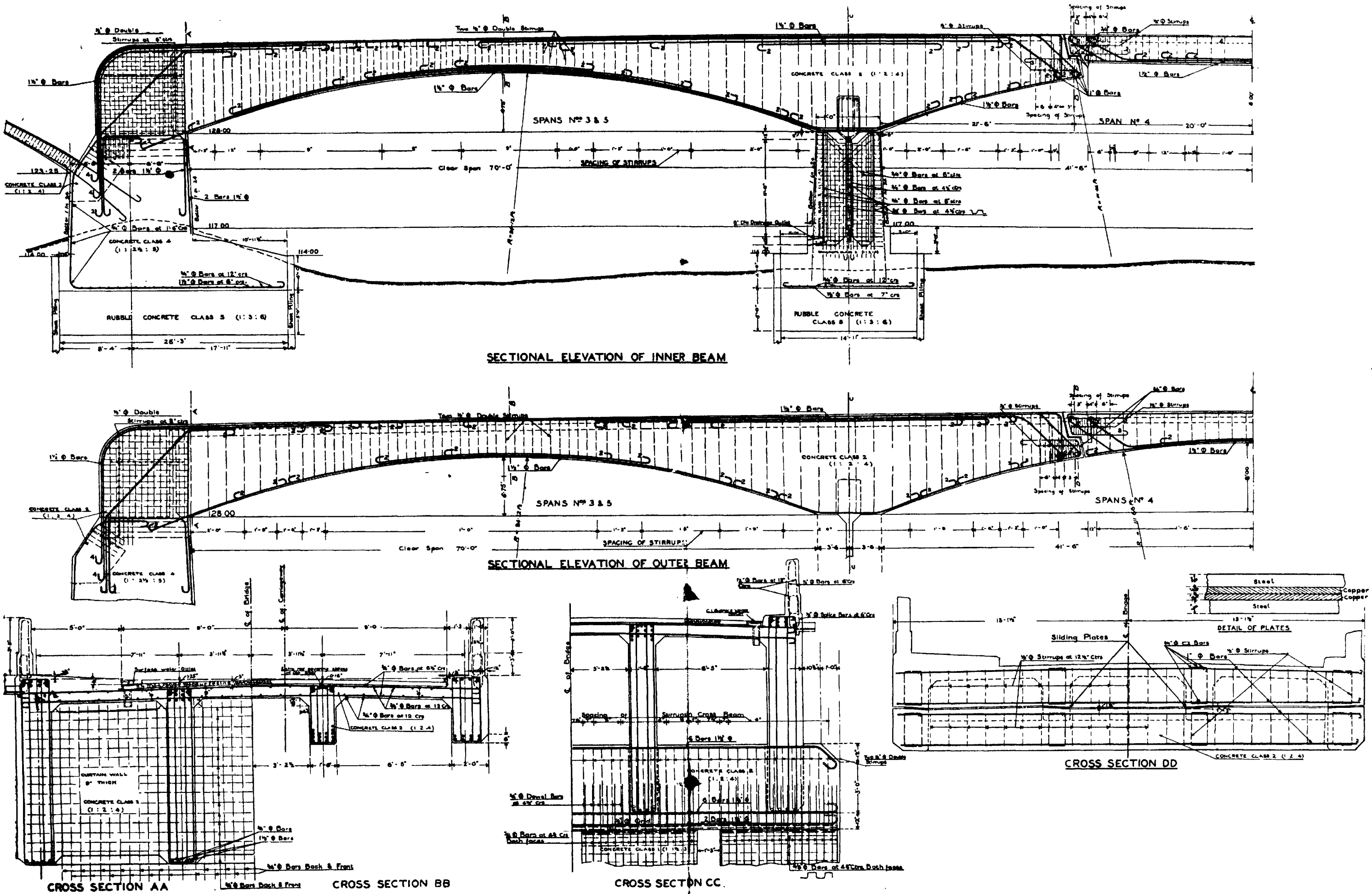


Fig. 155.—Bridge over River Orchy, Argyll.

These abutments are shoe-shape and of mass concrete designed to take the fixing moment from the side spans and also the thrust from the approach arches.

The river piers are cellular above foundation level and contain transverse flexible bearing walls 8 in. thick by 11 ft. high composed of 1 : 1½ : 3 concrete and reinforced on both faces with ¾-in. bars at 4½-in. centres; they are in four sections to allow for the construction of transverse walls bracing the pier sides, and bearing is transferred to them by means of transverse lintel beams 2 ft. 6 in. by 4 ft. deep, reinforced top and bottom. The bearing walls will act as columns fixed at the base, but with the other end free, the reinforcement being so arranged as to transmit no fixing moment at the surface of contact. The latter will be screeded accurately to the radius of possible movement. The walls will be deflected beforehand by wedging towards the centre of the river for a distance of ½ in. prior to casting the superstructure, in the anticipation that they will take up a more or less plumb position under normal conditions after initial shrinkage has taken place in the main beams.

Construction.

Preliminary borings were sunk over the site to a maximum depth of 60 ft., and from the information obtained a system of spread foundations was decided upon which will transmit a maximum bearing pressure of 2½ tons per square foot under the worst possible combinations of dead and live load. The foundations are being constructed within permanent cofferdams of steel sheet piling which will be cut off at approximately river bed level. They have been sealed under water with a 3-ft. layer of gravel concrete prior to pumping and completion in the dry. A recent view of the progress of the works is shown in *Fig.* 154.

Considerable attention has been paid to the architectural treatment of the exposed surfaces of the concrete work, and the bridge is being finished with a skin of concrete mixed with cream-coloured Portland cement, sand, and natural grave aggregate and generally placed by the employment of a sliding steel shutter. The coarse aggregate is graded from 2½ in. to ¾ in., the largest materials being placed nearest ground level and the grading diminished by ¼ in. at intervals in height of approximately 3 ft., the object being to obtain a gradual, but not apparently stepped, diminution in the size of the aggregate, finishing with ¾-in. gauge in the bridge parapets. A compound to retard the setting of the surface cement is first applied to the shutters, and with a liberal application and early stripping it has been possible to obtain a penetration of almost ¼ in. with wire brushing only; this is sufficient to expose the smaller aggregates but not sufficient for the larger, and resort has had to be made

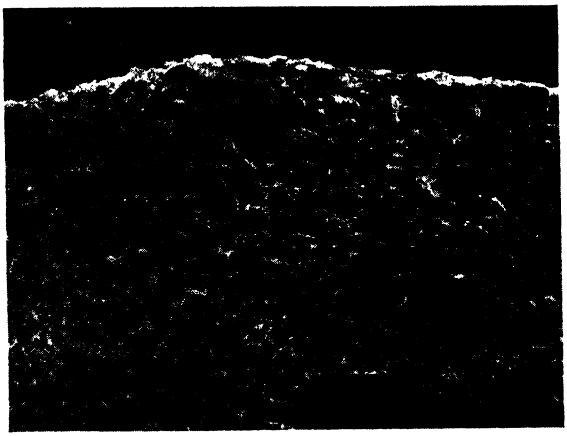


FIG. 156.—LARGE AGGREGATE EXPOSED BY RETARDING COMPOUND.

to supplementary hand chiselling. The effect of the exposure of the larger grade aggregate is shown in *Fig.* 156.

The architectural treatment of the bridge was carried out by Mr. T. S. Tait, F.R.I.B.A., of Sir John Burnet, Tait & Lorne, and the engineering side by the County Engineer's staff, Argyll County Council. The contractor is Mr. John McColville, of Cardiff.

AUCHALLATER BRIDGE, ABERDEENSHIRE

A Superelevated Deck.

AUCHALLATER BRIDGE, which carries the Perth–Devil's Elbow–Braemar Road (A93) over the Callater Burn two miles south of Braemar, was damaged practically beyond repair during a severe storm on January 24, 1937. The road is the highest main road in Britain and is snow-bound for the greater part of the winter, but is extensively used by tourist traffic during the summer season. The opportunity therefore was taken to carry out a considerable improvement of the alignment and width of the affected section of road by the construction of a new concrete bridge slightly downstream.

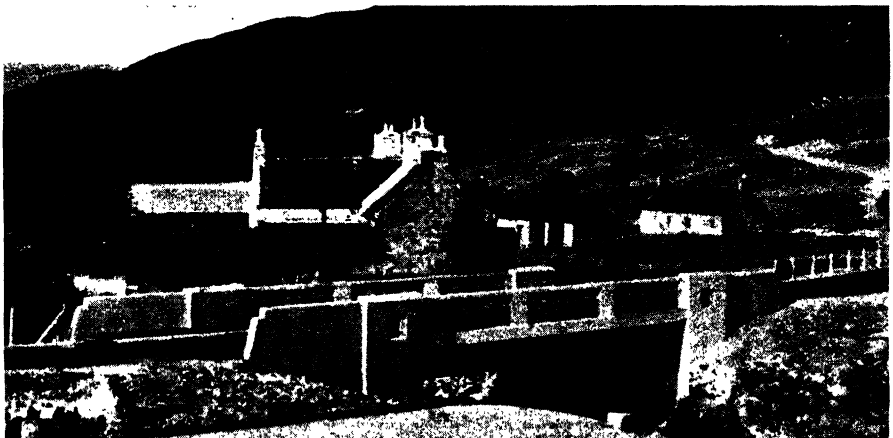


FIG. 157.—BRIDGE WITH SUPERELEVATED DECK IN ABERDEENSHIRE.

The new bridge (*Fig.* 157) provides an 18-ft. carriageway with a 5-ft. footpath and 1-ft. safety verge, ample dimensions for a Highland road of this nature. It is of the simply-supported beam type of 40 ft. clear span, and the abutments and wing walls are of mass concrete founded on rock. The deck consists of a 7½-in. reinforced concrete slab supported by five main beams each 3 ft. deep below the slab by 18 in. wide; as the bridge is on a curve the beams are adjusted in level to give the bridge deck 9 in. superelevation. The beams are simply supported but dowelled to the abutment at one end and at the other end supported on cast-iron rockers with steel bearing plates. The parapets are of reinforced concrete with recessed panels showing an exposed aggregate finish, all other exposed concrete work being rubbed down smooth with carborundum. The bridge was constructed by Messrs. Clark & Chapman, Aberdeen, to the design of Mr. M. Heddle, County Road Surveyor of Aberdeenshire. The total cost of the scheme, including roadworks, was £3,500.

ABERGARW BRIDGE, GLAMORGAN

Arch Vault of 50-ft. Span.

THE reconstructed river bridge at Abergarw, designed by Mr. E. Charles Pole, County Surveyor of Glamorgan, is a reinforced concrete arch vault on mass concrete abutments (*Figs.* 158–160). The arch is parabolic and has a clear span of 50 ft. and a rise of 10 ft. measured on the centre line of the vault. It is 10$\frac{1}{2}$ in. thick at the crown and 1 ft. 7$\frac{1}{2}$ in. thick at the springings, and the width between the parapets is 32 ft. 3 in. of which 22 ft. is occupied by the carriageway. For distances of 19 ft. 6 in. horizontally on both sides of the crown the longitudinal reinforcement is 1-in. bars at 6-in. centres both top and bottom. These bars overlap for a length of 4 ft. 6 in. with 1$\frac{3}{8}$-in. bars at 6-in. centres extending from the abutments. The transverse reinforcement consists of $\frac{5}{8}$-in. bars at 12-in. centres and is inside the layers of longitudinal bars and arranged so that the upper and lower transverse bars are staggered. At intervals of 1 ft. 6 in. there are $\frac{3}{8}$-in. single-leg links joining the upper and lower longitudinal bars two by two, and where the latter bars are lapped two shrinkage keys with grooved joints were left and concreted after the remainder of the arch vault had been completed.

The abutments are 13 ft. wide and 10 ft. high at the front and 4 ft. high at the back. At the bottom they are stepped up twice in 9-in. rises. The wing walls were also constructed in mass concrete. Over each abutment there is an expansion joint between the reinforced concrete spandrel wall and the mass concrete wing wall. The spandrel walls are 12 in. thick and are monolithic with the 10-in. parapet wall. On the inside they are reinforced with $\frac{1}{2}$-in. vertical bars at 7-in. centres in a length of 32 ft. symmetrical about the crown and beyond these points with $\frac{3}{8}$-in. bars at 7-in. centres. On the outside of the walls the vertical reinforcement is $\frac{3}{8}$-in. bars at 7-in. centres, and in both faces there are $\frac{1}{2}$-in. horizontal bars at 12-in. centres. Plan and sections of the wing wall are given on the next page. The reinforced concrete parapet is 10 in. thick and has a reconstructed stone coping, and the exposed faces of the parapet, spandrel walls, and vault have been bush-hammered.

The contractors for the reconstruction of the bridge were Messrs. Rees Jones & Sons, Ltd.

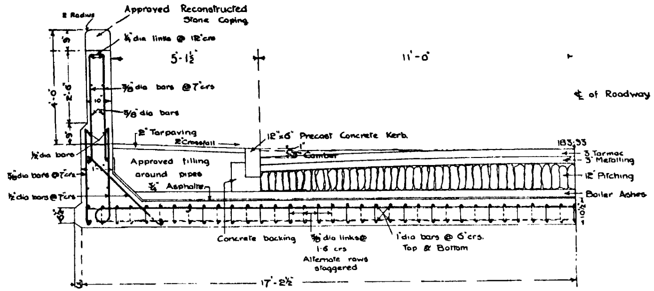


FIG. 159.—HALF CROSS SECTION OF DECK.

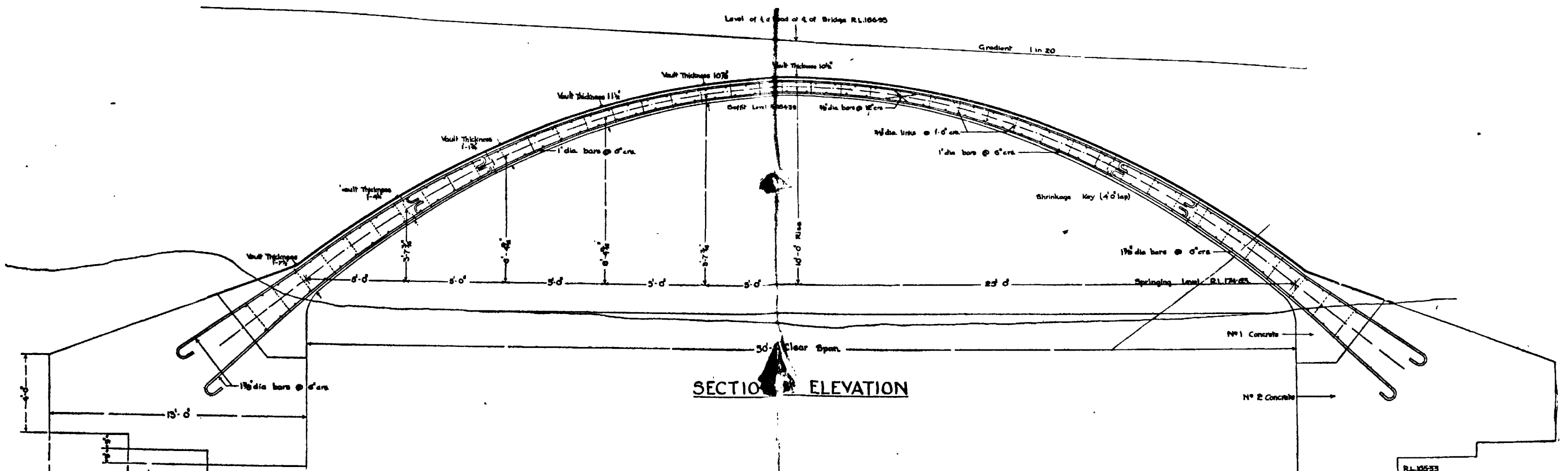


FIG. 158.

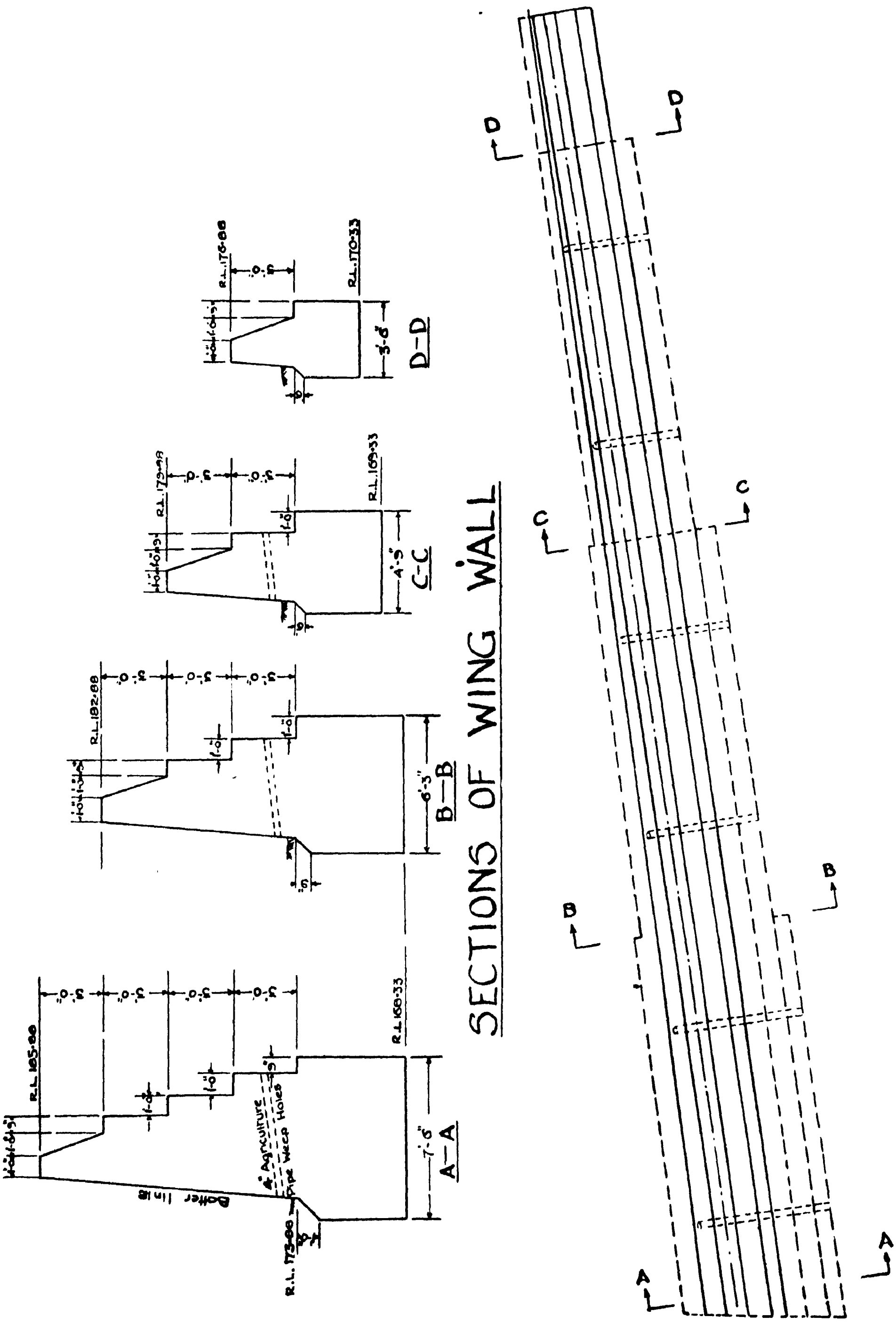


FIG. 160.—ABERGARW BRIDGE, GLAMORGAN: PLAN AND SECTIONS OF WING WALL. (*See previous page.*)

MOOR BRIDGE, NOTTINGHAM

Provision for Lifting in case of Subsidence.

THIS bridge will carry a 60-ft. double carriageway over the L.M.S. Railway and the river Leen in three spans totalling 110 ft., and is approached by earthwork embankments approximately 200 yd. long over the adjoining flood and marsh land. It replaces a near-by bridge which had been scheduled as weak, and which had dangerous approaches. The whole of the design and details, and supervision, are being carried out by Mr. R. M. Finch, M.Inst.C.E., City Engineer of Nottingham.

The approximate costs of the work are as follows: Bridge (excluding roadworks), £17,000; approaches (excluding roadworks), £13,000; roadworks, £8,000; river protection and culvert works, £2,000. The contractors are the Holborn Construction Co., Ltd., for the bridge, approach and culvert works, and The Butterley Co., Ltd., for welded steelwork; the roadworks are being done by the Nottingham Corporation Highways Department. Views of the bridge under construction are shown in *Figs.* 161 and 162.

The general lines of the bridge follow the curve of the roadway, emphasis to this curve being given by recessed bands in the elevation. The elevations are entirely in concrete, the surface being formed of khaki "Colorcrete" to blend with the prevailing local stone. This is cast in situ with the backing concrete, from which the facing is separated by expanded metal. The elevations and parapets are to be bush-hammered to reveal the Trent gravel aggregate.

The structural design comprises two intermediate trestles of lightly-reinforced columns carrying a lintel-beam, and two abutments formed of reinforced concrete counterfort walls, the ends of these being returned parallel to the roadway to form wing walls of the vertical cantilever type. It was found convenient to form the counterforts, which are of framed section, as pre-cast units, each weighing 4½ tons, and these were placed in position with screw jacks. The base-beams incorporating the pre-cast units into the base slab were then cast, and the front wall cast up to them.

FIG. 161.—TRESTLES AND ABUTMENTS.

The shoulders of the approach embankments are brought round to intersect the wing walls. The presence of culverts beneath the latter led to the outer ends of these being cantilevered horizontally to shorten the foundations (shown partially completed in *Fig.* 161) and the result has given an economical substructure.

The bridge deck is of two types, the river span being of reinforced concrete and the railway spans of welded steel plate girders. Steel was selected for the latter owing to the small construction depth and working space available. The deck is of in situ concrete carried on precast concrete jack-arches of 4 ft. 3 in. span by 2 ft. long. These were formed in steel moulds on the site. The arches are carried on skew-backs formed by precasting on to the girders a concrete casing to the bottom flange, the maximum weight

of one girder being 4 tons plus 4 tons of concrete.

The river span is a 24-in. thick reinforced concrete slab of 1 : 1½ : 3 mix, and the service ducts beneath the footpaths are formed throughout of in situ concrete.

The parapets are of in situ concrete, the footpath elevation being of coloured concrete, bush-hammered and relieved by two glazed-tile bands. On its outer face the parapet will be protected from smoke by pre-cast reinforced concrete canopies projecting approximately 3 ft.

Considerable work was necessary in the foundations of the bridge, which were constructed in cofferdams, the foundations being taken to a limestone bed about 13 ft. below water-level.

For concrete Trent gravel aggregate of ¾ in. maximum size and Trent sand were used. In the elevations, where sharp arrises are required to the channel bandings, a gravel of ½ in. maximum size is used, and precautions are taken to ensure a consistent supply and mix in view of the use of coloured concrete. The reinforcement is delivered bent to the site.

Provision for Jacking.

The principal feature of the design is necessitated by the possibility of colliery subsidence, the locality being subjected to falls of several feet. The bridge was therefore designed as a group of separate units, and the abutments and trestles are each divided into halves. Each span is simply supported, and the whole of the deck is divided by bituminous felt strips into six portions by a continuous joint along the central verge and transverse joints between the three spans. Ledges are formed on the abutments, and concrete brackets on the intermediate pillars, for the purpose of placing hydraulic jacks (*Fig.* 162). Should subsidence occur, and re-grading of the railway line become necessary, the whole of the bridge deck can be lifted to maintain the necessary headroom.

The whole of the scheme was completed in the summer of 1939.

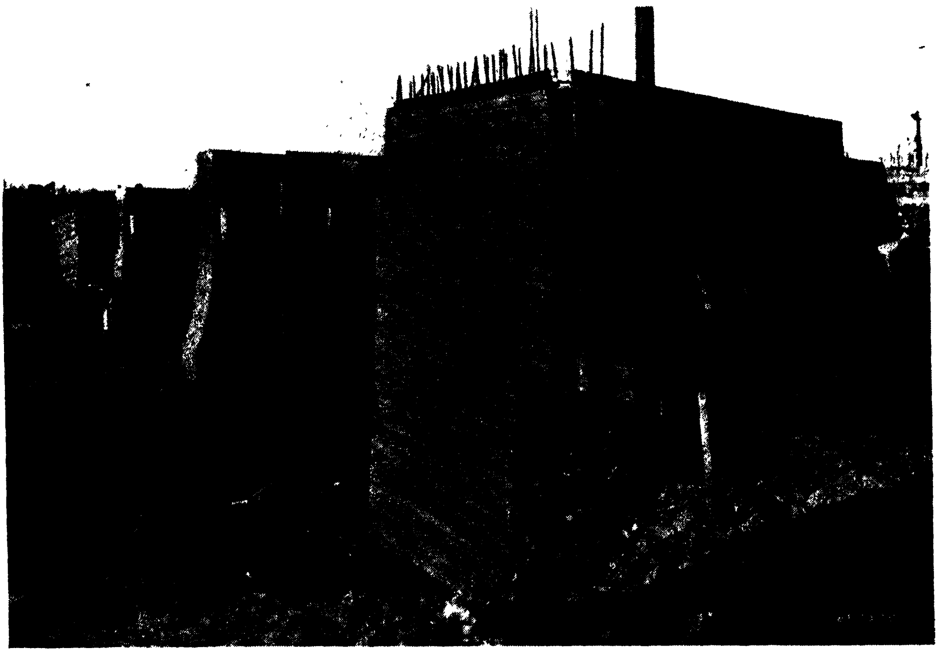


FIG. 162.—SHOWING LEDGES AND BRACKETS TO CARRY HYDRAULIC JACKS.

RECONSTRUCTION OF WICK SERVICE BRIDGE

At Wick a plate-girder bridge of seven spans built fifty years ago has recently been replaced by a reinforced concrete bridge of three spans. The original bridge was built as a temporary structure when the bridge on the main road to John o' Groats, farther up the river, was being reconstructed—hence the name " Service Bridge." From time to time it had been strengthened and widened as it was found to be still useful as an access to the harbour, but in 1936, when it became necessary to close the bridge to vehicular traffic, the County Council resolved to replace it. The new bridge (*Fig.* 163) is a three-span continuous girder type with four ribs at 9-ft. centres carrying a 10½-in. floor slab. The middle span is 74 ft. long between the centres of the piers, and each side span is 60 ft. between the face of the abutment and the centre of the pier. Between the parapets the width is 32 ft., allowing space for a 20-ft. road and two 6-ft. paths.

Fig. 163.

Foundations.

Bores were put down along the proposed line of the new bridge. On the north side of the river rock was found just below the river bed, but the strata sloped very steeply towards the south side where it was found that the rock level had fallen about 25 ft. in a horizontal distance of 200 ft. To overcome the difficulty of the depth at which the rock lay, 14-in. by 14-in. reinforced concrete piles were used in the foundations at the south abutment and south pier. As trouble was anticipated in driving the piles owing to the number of large boulders present, a water jet was embodied in the piles. This greatly facilitated driving and with its aid a 2-ton semi-automatic steam hammer was able to drive the piles without difficulty. Asbestos cushions were used in the driving helmet and no case of fractured pile heads occurred.

Cofferdams of No. 2 Larssen steel sheet piling were constructed at the piers and at the south abutment. In some cases such great difficulty was experienced in driving the sheeting owing to the presence of boulders that the excavation had to be carried down simultaneously with the driving and the large stones removed from beneath the piles.

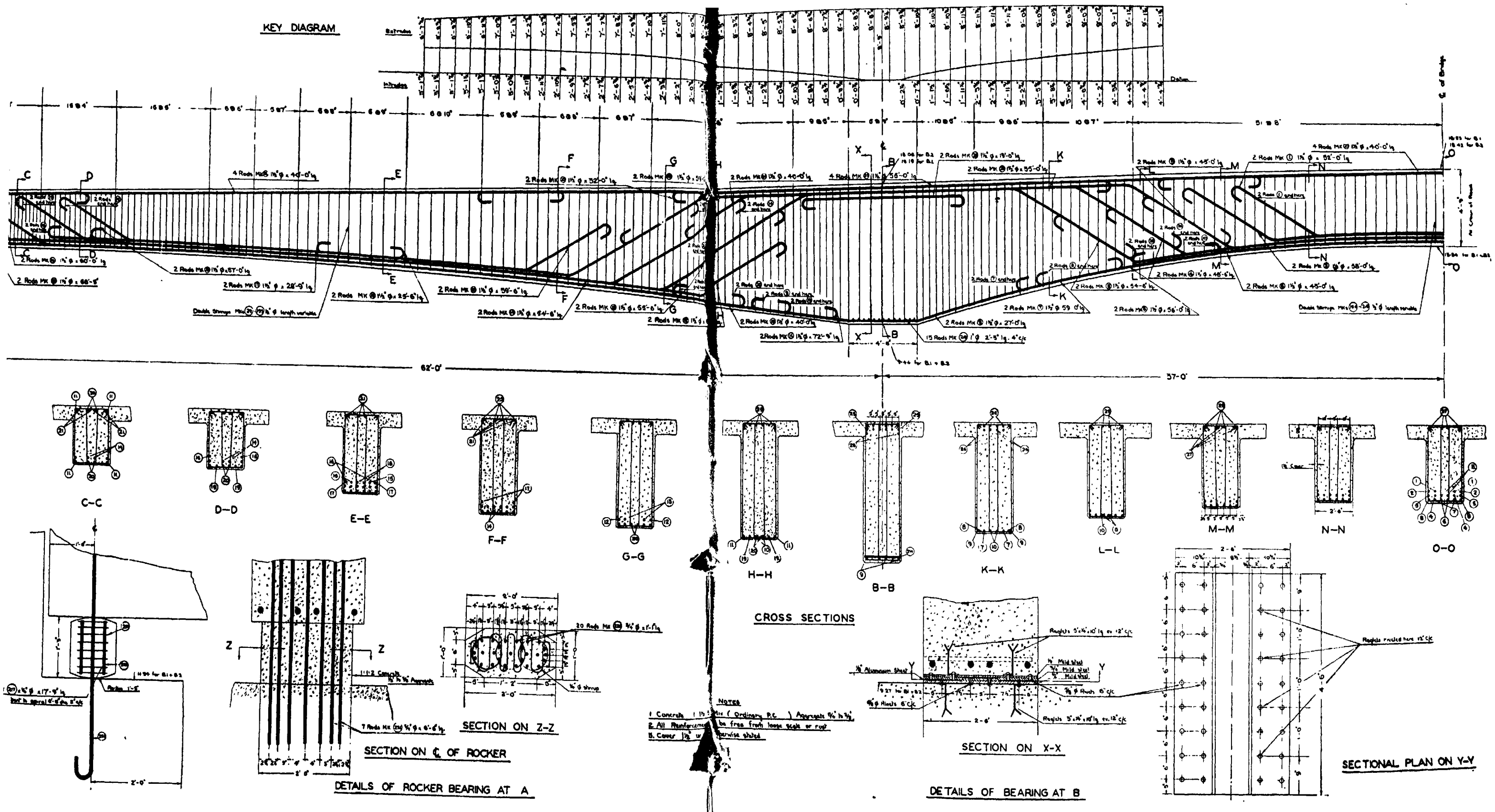


FIG. 164.—RECONSTRUCTION OF WICK SERVICE BRIDGE.

Aggregates and Concrete.

For the mass concrete work a 1 : 2 : 4 mix was adopted and for the reinforced concrete a 1 : 1½ : 3 mix. The sand was dredged from the entrance to Wick harbour and is the most suitable fine aggregate obtainable in the district, as there is no convenient supply of pit sand and the beach sands round the coast are too fine and contain a very high proportion of broken shells. The coarse aggregate was for the most part crushed whinstone, quarried locally. The only objection to this stone is that the small particles are apt to be thin and flat, owing to the laminated structure of the stone.

Six-inch test cubes were made from the concrete placed in the work, and highly satisfactory results were obtained by compression tests made in the engineering laboratories at Edinburgh University. The average breaking stress was 5,200 lb. per square inch.

The Superstructure.

On completion of the piers and abutments the centering for the main beams was erected. At the north side 12-in. by 12-in. timber piles were driven to rock, but at the south side the main supports were carried on mass concrete foundations. Details of the reinforcement in the main beams are shown in *Fig.* 164, which also illustrates the shape of these beams in elevation and the design of the bearings at the ends.

The side spans were concreted first, the concrete being carried 8 ft. past the pier into the middle span, this being the most convenient point for a vertical joint having regard to the positions of the 1½-in. diameter bars in the beams. The beams were poured in one lift to the soffit of the deck slab to avoid making a horizontal joint in the beam which might prove a source of weakness. A pneumatic vibrating tool, working on the bars and the shuttering, was in use throughout the concreting period.

At the piers sliding bearings were provided for the beams, aluminium sheeting ⅛ in. thick being placed between the mild steel galvanized bearing plates which were secured to the pier and beam by 3-in. by ¼-in. raglets 10 in. long. Rocker bearings were placed at the abutments. The deck slab was poured in 15-ft. panels, this being a convenient length for screeding.

The parapet, originally intended to be in freestone, was constructed in reinforced concrete with a 9-in. dressed freestone cope. The concrete was poured in 18-ft. panels with a layer of bitumen at each joint to prevent cracks occurring due to settlement or temperature stresses. On the deck a 1-in. thickness of bitumen insulation is to be applied before laying the 4 in. of "Carpave" surfacing. The kerbs are pre-cast concrete 12 in. by 6 in. in cross section.

The superstructure of the bridge has been rendered with light-cream Cullamix with a scraped finish. Before applying the facing the concrete was rendered with a ⅜-in. coat of water-repellent Portland cement which was well scored to provide a key for the rendering.

The consulting engineers for the work were Messrs. Blyth & Blyth, MM.Inst.C.E., who collaborated with Mr. Cameron Sutherland, County Surveyor of Caithness. The work was carried out by Messrs. H. M. Murray & Co., of Glasgow.

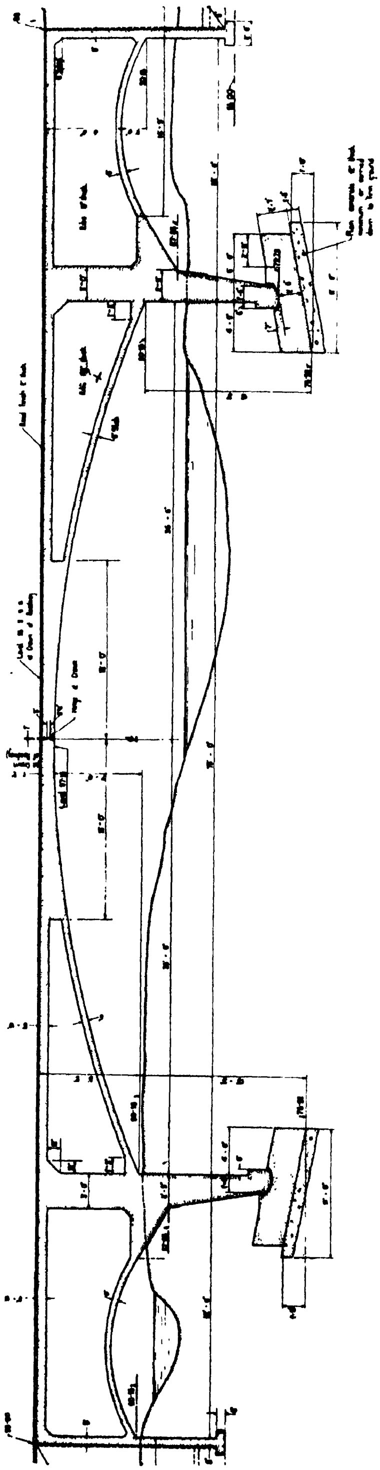


FIG. 165.—LONGITUDINAL SECTION THROUGH ROADWAY.

ABERUTHVEN BRIDGE, PERTH AND KINROSS

Cellular Portal Frame.

THIS bridge (*Fig.* 165) is being constructed to carry route A9 over the river Ruthven.

The new bridge will be 40 ft. wide between the parapets and there will be a 30-ft. carriageway with two 5-ft. paths, under one of which will be a pipe duct covered with 2-in. pre-cast concrete slabs 2 ft. square.

The construction consists of a three-hinge cellular portal main span, providing a generous waterway, with a flood arch at each end constructed monolithically with the main span to provide the necessary stabilising moments. The main span is 73 ft. in the clear and has a rise of 7 ft.

For the length of 15 ft. on either side of the crown the slab is solid, increasing in thickness from a minimum of 14 in. at the crown hinge. In the remainder of the 73-ft. span there are a top and a bottom slab connected by longitudinal ribs 9 in. wide and spaced 9 ft. apart. The joint at the crown hinge is 1 in. wide. A longitudinal section through the roadway is shown in the illustration. The bridge will be faced with natural stone.

The authority for whom the bridge is being reconstructed is the Perth and Kinross County Council, for whom Mr. Wm. Kirkland, M.Inst.M. & Cy.E., is the District Road Surveyor. The consulting engineers are Messrs. F. A. Macdonald & Partners (Glasgow), Ltd. The cost of the complete scheme is approximately £13,800. The contractors are Messrs. William Taylor & Son (Glasgow), Ltd.

STANNINGTON ROAD BRIDGE, SHEFFIELD

Two 32-ft. 6-in. Skew Spans.

THIS bridge (*Fig.* 166) replaces a narrow stone arched structure only 21 ft. wide which was built in 1864. The new bridge consists of two 32-ft. 6-in. skew spans crossing the river Loxley at an angle of 50 deg. It is 40 ft. wide between the parapets and carries a 30-ft. road and two 5-ft. paths. The abutments, wing walls, and middle pier are built of 1 : 3 : 5 mass concrete behind masonry facing with an average thickness of 12 in. The whole of the facework is also masonry.

In the reinforced concrete deck (*Fig.* 167) the slab is $7\frac{1}{2}$ in. thick and is supported on five road beams and two kerb beams spaced at 5-ft. centres. These beams are 37 ft. 6 in. long and, including the slab, are 2 ft. 10 in. deep. They are simply supported at the ends and reinforced at midspan with eight $1\frac{5}{8}$-in. bars in the bottom. In the road beams there are two $\frac{3}{4}$-in. bars in the top; in the kerb beams there are eight $1\frac{5}{8}$-in. bars in the top, but four of these are cut off at 7 ft. from the end. The main transverse reinforcement in the slab is $\frac{5}{8}$-in. bars at 5-in. centres both top and bottom. Outside the kerb beams, and 4 ft. 6 in. from them, there are footway beams carrying one end of the floor of the pipe ducts and the paths above them. These beams are 3 ft. 2 in. deep by 12 in. wide and are reinforced at midspan in the bottom with six $1\frac{5}{8}$-in. bars and in the top with two $1\frac{5}{8}$-in. bars.

The bridge was designed by the former City Engineer (Mr. W. J. Hadfield, C.B.E.). The present City Engineer is Mr. R. Nicholas, B.Sc., M.Inst.C.E. The bridge was built by Messrs. Wellerman Bros., Ltd.

FIG. 166.

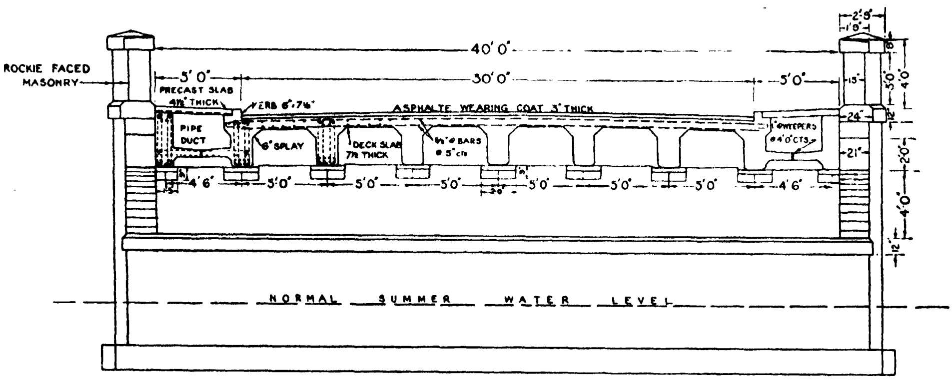


FIG. 167.—DETAILS OF DECK.

HEUGH STREET BRIDGE, SOUTH SHIELDS

The Design of a Bowstring Bridge.

THIS is a reinforced concrete bowstring bridge with a clear span of 164 ft. over the London & North Eastern Railway. The headroom provided is 30 ft., and the bridge carries a 29-ft. carriageway and two footpaths each 9 ft. wide, below which service ducts are provided.

The decking is of the usual beam-and-slab type in which the slab spans between longitudinal secondary beams ; the latter bear on transverse beams which are carried on the bottom horizontal ties of the bowstring girders and project beyond the two ties to form cantilevers to carry the paths. Each horizontal tie is at deck level and connects the ends of the parabolic top rib. The lower member is suspended from the curved upper boom by vertical hangers.

The whole of the superstructure is supported on four cast-steel bearings placed under the ends of the bowstring girders, two of the rocker type at one end, and two of the rocker-roller type at the other end. The bearings are situated in recesses at the top of the abutment walls. The rocker bearings and the rocker-roller bearings were so designed that the load on the concrete under the bearing areas did not exceed 1000 lb. per square inch. Both types of bearings are arranged so that they will be completely boxed in, and it is intended to fill them with grease to prevent them rusting.

The abutment walls and flanking wing walls are of reinforced concrete founded on strong brown clay and present no special features of interest.

The deck is drained by twelve reinforced concrete gully traps connected to 6-in. drains in the service ducts under the footpath which carry the water to adjacent manholes. Dry stone drains and weepholes drain the abutment and wing walls.

The illustrations show two stages in the erection of the superstructure ; in *Fig.* 168 the shuttering is in position for a portion of the curved rib, and in *Fig.* 169 the first section of the rib is finished and the shuttering has been stripped.

FIG. 168.

Superload, Stresses, and Design.

The bridge is designed to carry the Ministry of Transport Standard Loading. The whole of the decking and abutments are designed for stresses of 800 lb. per square inch on the concrete in compression and 16,000 lb. per square inch on the steel in tension. The concrete mix is 90 lb. of cement to 2 cu. ft. of sand and 4 cu. ft. of coarse aggregate. The bowstring ties are designed for stresses of 1200 lb. per square inch on the concrete in compression and 16,000 lb. per square inch on the steel in tension, and the concrete mix in these members is 180 lb. of cement to 2 cu. ft. of sand and 27 cu. ft. of coarse aggregate.

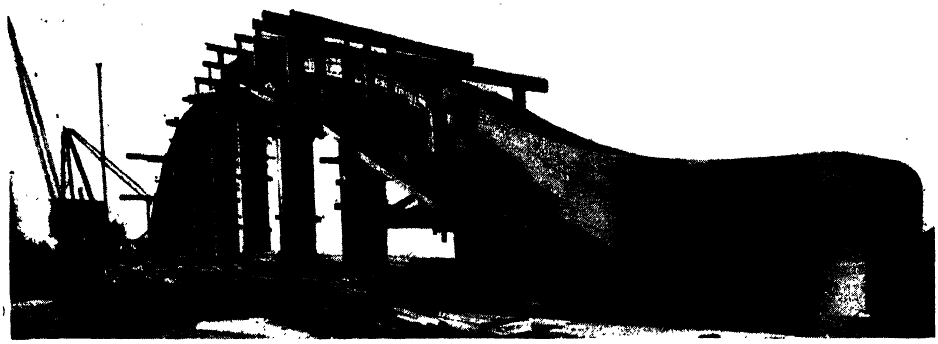


FIG. 169.

The vertical suspenders are increased in width towards the lower end and are designed to take the overturning moment produced by the wind pressure acting on the curved boom and the suspenders. In addition, the horizontal pressure transmitted to the deck platform by the ties and the total wind pressure produced by the wind acting upon both girders simultaneously were investigated. The maximum lateral bending moment upon the whole structure produced by these conditions was about 2½ million ft.-lb., and additional steel was provided throughout the full length of the bridge at each parapet to provide for this increased tension.

Details of the Curved Rib.

For purposes of design the curved rib member was considered as a two-hinged parabolic arch, but temperature stresses were not considered as any change in the length of the curved rib causing the span to vary is permitted by rotation of the bearings.

In designing the parabolic member account was taken of the bending moment caused by the elastic extension of the horizontal tie and the bending moment induced by arch shortening. The stresses in the parabolic arch member were investigated at three points, that is, at the middle, the third-point, and the fourth-point. The maximum bending moment and thrust, as is usual in bowstring girders, occurs at the top of the third suspender. The bowstring was designed for a live load of 220 lb. per square foot over the whole area of the roadway and 2 cwt. per square foot over the area of the footways, together with the invariable knife-edge load of 2700 lb. per lineal foot acting transversely to the bowstring at the position on the influence line where it creates the maximum bending moment or thrust. The maximum bending moment was found to be 2½ million ft.-lb. and the maximum normal thrust 2 million ft.-lb. The total dead and live load on the whole bridge under maximum conditions of load is about 3000 tons.

The curved ribs are 5 ft. 6 in. by 4 ft. 6 in. in section at the springings and 4 ft. 6 in. by 4 ft. 6 in. in section at the crown, and are recessed 15 in. by 18 in. on each side throughout the length. The longitudinal reinforcement varies from thirty-six 1¼-in. bars at the crown to

fifty-four 1⅜-in. bars at the third-point, and then to thirty-six 1¼-in. bars and eighteen 1⅜-in. bars at the springing.

Design of the Horizontal Ties and Suspenders.

The horizontal ties were designed to resist the action of the tension due to the horizontal thrust from the curved ribs, and as the moment of inertia of the tie is considerable the resistance to the bending moment caused by vertical loading was apportioned between the curved rib and the tie in direct proportion to their respective moments of inertia. The ties are 4 ft. 6 in. by 4 ft. 10 in. in section and are reinforced with 100 1⅜-in. bars. These bars are not lapped but jumped up to 1⅝-in. diameter and threaded, butt jointed, and connected by screwed sleeves. The maximum tension on the ties is 2½ million lb. and the proportional bending moment carried is 1⅛ million ft.-lb.

Since the vertical suspenders were designed so that the whole of the tension is carried by the steel, a low working stress of 12,000 lb. per square inch was adopted. The bending moment produced by the wind was combined with the tension produced by vertical loading. The suspenders are flexible in the plane of the girders, as it is desirable that they should, without undue resistance, accommodate themselves to the relative movement between the rib and the ties. Their section is 12 in. by 42 in. at the foot, decreasing to 12 in. by 30 in. at the curved rib, and they are reinforced with nine 1⅝-in. bars on each face. The maximum load carried by each vertical suspender is about 150 tons, and the bending moment is 92,000 ft.-lb.

Abutment Design.

The abutments and wing walls are of the counterfort type. The stability of the abutments was investigated under three conditions:

(1) With the abutments only completed (without any bridge superstructure built) the weight of each abutment, including the filling, is about 2000 tons, and the maximum load on the ground is 1¾ tons per square foot.

(2) With the dead load only of the bridge acting, the maximum inclusive load on each abutment is about 3000 tons and the consequent maximum load on the ground is 3¼ tons per square foot.

(3) In the condition where the abutments are subjected to the whole dead and live load from the bridge, the total load including the weight of the abutments, the filling, and the dead and live loads is about 3700 tons and the consequent maximum load on the ground is 3¾ tons per square foot.

In calculating the stability of the abutments the angle ϕ was assumed to be 35 deg. in the Rankine formula for lateral pressure and the weight of the earth assumed to be 120 lb. per cubic foot.

The slab at the base of the abutments is 3 ft. 6 in. thick and is reinforced across the bottom and into the cantilever toe with 1½-in. bars at 6-in. centres, and between the counterfort and heel with ⅞-in. bars at 7-in. centres top and bottom. In addition, a beam is formed in the thickness of the slab between the counterforts to carry the cantilever toe; this beam is reinforced with twenty 1⅛-in. bars at the top. The thickness of the curtain walls is 14 in. at the bottom and 9 in. at the top, and the reinforcement consists of alternate straight and curved bars ⅞ in. in diameter at 4-in. centres at the bottom, decreasing to ⅝-in. bars at 6-in. centres at the top. The counterforts generally are 18 in. thick and are reinforced with ten 1⅜-in. bars at the back face. The total bending moment on the counterforts is about 5 million ft.-lb. The counterforts directly underneath the rocker and roller bearings are increased in thickness to 36 in. and are reinforced with eight 1⅜-in. bars on each face.

Materials and Quantities.

The total amount of concrete in the work is 2500 cu. yd. The aggregate is specified to be gravel, shingle, or broken stone of a hard close-grained and durable nature, varying from ⅛-in. to ¾-in. gauge. The sand is specified to be clean sharp river or pit sand, coarse and graded from ⅛ in. downwards. The total weight of the reinforcement is 470 tons.

The bridge is being constructed in accordance with the plans of Mr. John Reid, M.Inst.C.E., Borough Engineer of South Shields. The consulting engineers are Messrs. L. G. Mouchel & Partners, Ltd., and the contractors are the Yorkshire Hennebique Contracting Co., Ltd.

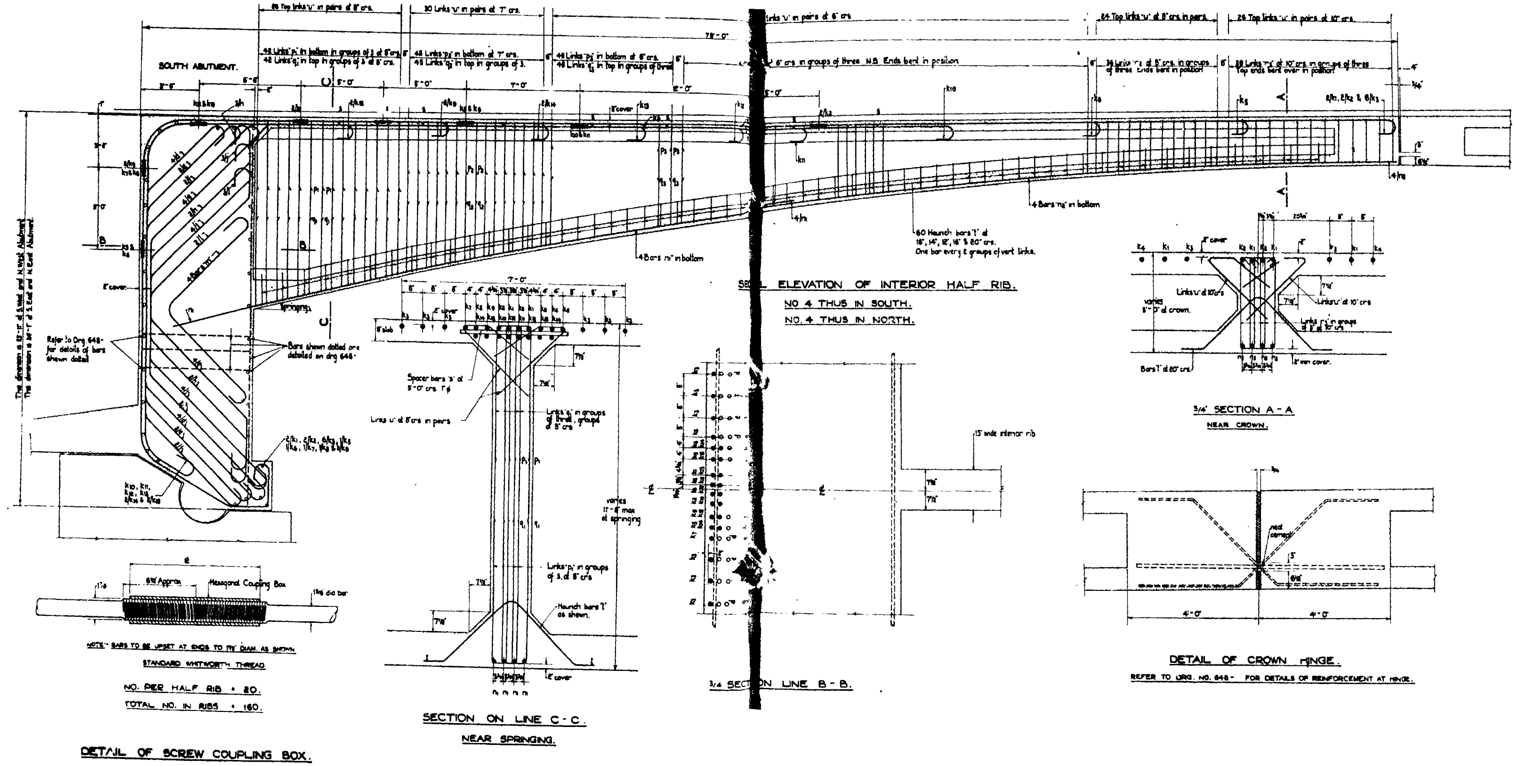


Fig. 170.—New Bridge at Bridge of Allan: Detail Interior Rib. (The key to the bars is given in *Fig.* 172.)

BRIDGE OF ALLAN

140-ft. Span Portal Frame.

This bridge is to be constructed to carry route A9 over the river Allan at Bridge of Allan, near Stirling. It was necessary to provide the minimum construction depth at the crown, and as the rise could only be between 9 ft. and 10 ft. for a clear span of 140 ft., three-hinge portal frame construction was adopted. The bridge is to be constructed in two portions, with a sliding joint between, in order to permit the road to be kept open throughout construction. The elevation will be faced with natural stone. Details of reinforcement are on the previous and following pages.

The bridge (*Figs.* 170–172) was designed by Messrs. F. A. Macdonald & Partners (Glasgow), Ltd., and the collaborating architect is Mr. James Shearer. Mr. John Schoolar is the County Road Surveyor.

Between the parapets the new bridge will be 64 ft. wide with two 20-ft. carriageways separated by a 6-ft. verge. The footpaths will be 9 ft. wide and there will be a pipeduct 2 ft. deep under each. In the design of the superstructure the cellular principle was adopted with longitudinal ribs 15 in. thick spaced at approximately 7-ft. 9-in. centres and varying in depth from 3 ft. near the crown to 11 ft. 8 in. at the face of the abutments. The deck slab is 8 in. thick and the lower slab varies in thickness from 8 in. near the crown to 10 in. on the haunches and 12 in. at the abutments. On both sides of the crown the rib is solid for a length of 4 ft. and 3 ft. thick.

The abutments are 7 ft. thick and have a projecting heel slab 13 ft. long and a semicircular concrete hinge of $18\frac{1}{2}$ in. radius capable of turning in a semi-circular groove formed in the upper side of the foundation block. The curved space at the concrete hinge is filled with a contact layer of bitumen sheeting varying in thickness from $\frac{1}{2}$ in. to $\frac{1}{8}$ in. The plane joint between the foundation and the abutments is filled with 1-in. compressed cork sheeting fixed with Masticon.

The principal reinforcement in the abutments and ribs is $1\frac{5}{8}$ in. in diameter. In each interior half-rib there are twenty joints on these bars in which coupling boxes are used to make the connections. An extra allowance of 3 in. is made on the length of a bar to allow for making the upset threaded end.

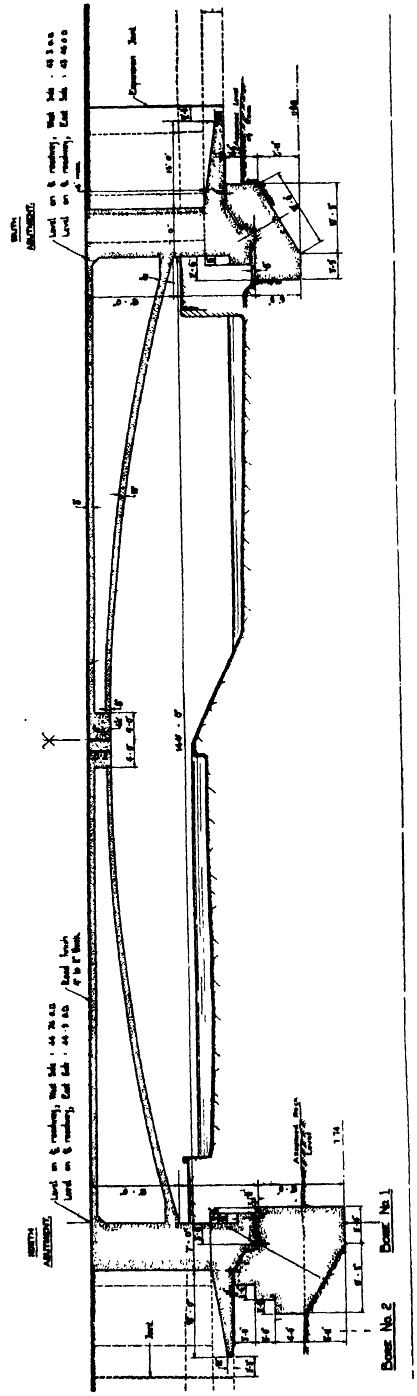


Fig. 171.—New Bridge at Bridge of Allan: Longitudinal Section on Centre Line.

SCHEDULE OF STEEL REINFORCEMENT.

PART	NO.	GROUP REF	BAR	NO.	TOTAL NO.	DIA	LENGTH	BENDING
INTERIOR LONGITUDINAL RIBS	8	K_1	a	2	16	1 5/8"	41' - 9"	
			b	2	16	1 5/8"	29' - 6"	
			c	2	16	1 5/8"	41' - 3"	
		K_2	a	2	16	1 5/8"	46' - 9"	As bar K_1a but dimension x = 12' - 4"
			b	2	16	1 5/8"	29' - 6"	As bar K_1b
			c	2	16	1 5/8"	36' - 3"	
		K_3	a	6	48	1 5/8"	29' - 3"	
			b	6	48	1 5/8"	47' - 0"	
			c	6	48	1 5/8"	48' - 9"	
		K_5	a	1	8	1 5/8"	25' - 0"	
			b	1	8	1 5/8"	27' - 3"	
			c	1	8	1 5/8"	51' - 0"	
		K_6	a	1	8	1 5/8"	25' - 0"	As bar K_5a
			b	1	8	1 5/8"	27' - 3"	As bar K_5b
			c	1	8	1 5/8"	42' - 0"	
		K_7	a	1	8	1 5/8"	32' - 0"	As bar K_5a but dimension x = {16' - 0" on west; 16' - 2" on east}
			b	1	8	1 5/8"	40' - 0"	
		K_8	a	1	8	1 5/8"	30' - 0"	As bar K_5a but dimension x = {16' - 0" on west; 16' - 2" on east}
			b	1	8	1 5/8"	34' - 0"	
		K_9	a	2	16	1 5/8"	30' - 0"	As bar K_5a but dimension x = {16' - 0" on west; 16' - 2" on east}
			b	2	16	1 5/8"	22' - 0"	
		K_{10}	a	1	8	1 5/8"	50' - 0"	
			b	1	8	1 5/8"	26' - 6"	
		K_{11}	a	1	8	1 5/8"	50' - 0"	As bar $K_{10}a$
			b	1	8	1 5/8"	17' - 6"	
		K_{12}	a	1	8	1 5/8"	26' - 6"	As bar $K_{10}a$ but dimension x = 0' - 10"
			b	1	8	1 5/8"	35' - 0"	
		K_{13}	a	1	8	1 5/8"	26' - 6"	As bar $K_{10}a$ but dimension x = 0' - 10"
			b	1	8	1 5/8"	29' - 0"	

MEMBER	NO.	GROUP REF	BAR	NO	TOTAL NO	DIA	LENGTH	BENDING
INTERIOR LONGITUDINAL RIBS (CONTD)	8	K_{14}	a	2	16	1 5/8"	49' - 0"	
		K_{15}	a	2	16	1 5/8"	36' - 0"	As bar $K_{14}a$ but dimension x = 10' - 0"
			d	4	32	1 5/8"	30' - 3"	
			e	2	16	1 5/8"	30' - 3"	
			f	2	16	1 5/8"	31' - 0"	
			g	4	32	1 5/8"	27' - 6"	
			h	2	16	1 5/8"	29' - 6"	
			j	4	32	1 5/8"	28' - 3"	
			l	2	16	1 5/8"	27' - 9"	
			m	4	32	1 5/8"	16' - 6"	
			n_1	4	32	1 1/4"	41' - 0"	Curved to Radius
			n_2	4	32	1 1/4"	41' - 0"	Curved to radius
			p_1	12	96	1/2"	12' - 5"	Upright Links; varies; in groups of three links
				12	96		13' - 5"	
				12	96		14' - 5"	
				6	48		15' - 3"	
			p_2	15	120	1/2"	10' - 9"	Do; varies; Do
				15	120		12' - 0"	
				15	120		13' - 0"	
			p_3	15	120	1/2"	10' - 6"	Do; varies; Do
				15	120		11' - 9"	
				18	144		12' - 9"	
			q_1	42	336	1/2"	12' - 9"	Inverted Links; varies; Do
			q_2	45	360		10' - 9"	
			q_3	48	384		7' - 3"	
			r_1	[illegible]	[illegible]	1/2"	[illegible]	Bend over top ends of links in position; Equal; Equal; Three links per group; Links at 2" crs
			r_2	18	144	1/2"	8' - 0"	
				18	144		7' - 9"	
			r_3	39	312	1/2"	7' - 6"	
			s	8	64	1"	3' - 3"	Spacer bars in top of beam at 5' - 0" crs. Cut from 5 bars 1" ϕ 43' - 0" long.
			t	60	480	3/8"	6' - 6"	
			u	250	2000	7/16"	3' - 3"	

FIG. 172.—BRIDGE AT BRIDGE OF ALLAN. KEY TO REINFORCEMENT SHOWN IN FIG. 170.

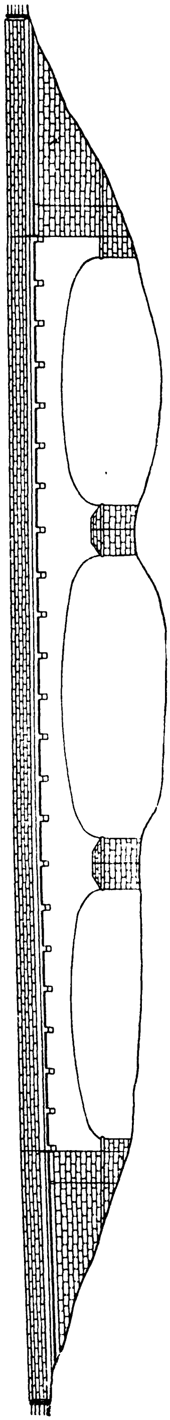


FIG. 173.—ELEVATION.

CRATHIES BRIDGE, MEIGLE

Widening and Strengthening on existing Foundations.

THIS scheme is one for widening and strengthening a bridge on existing foundations on the Alyth–Dundee road (A927). It provides for the elimination of a hump on the existing bridge and an increase in the width of the highway. The existing three-span masonry bridge of hollow construction is to be demolished down to springing level. The existing piers and abutments are in excellent condition and provide a good support for the new superstructure. The new construction (*Fig.* 173) is of the conventional curved beam type with three spans.

The spans will be 49 ft. 3 in., 55 ft. 6 in., and 49 ft. 3 in., and the rises 5 ft. 8 in., 7 ft. 2 in. and 7 ft. 4 in. respectively. In the cross-section there will be two ribs 1 ft. 9 in. wide and two 21-in. by 15-in. parapet beams. The cross beams will be 18 in. deep below the 9-in. reinforced concrete slab and 9 in. wide. They will be spaced at 8-ft. centres and cantilevered beyond the main ribs to carry two footpaths. Between parapets the width will be 30 ft. The road will be 20 ft. wide.

At the outer ends of the side spans sliding joints will be formed between the ribs and the abutments. Above the piers, which are 10 ft. wide, there will be reinforced concrete distributing beams 3 ft. 3 in. deep. The exposed concrete surfaces on the elevations will be finished with a scraped "Keytex" treatment, and all exposed arrises will be chamfered.

The consulting engineers are Messrs. F. A. Macdonald & Partners (Glasgow), Ltd., and the engineer responsible for the scheme is Mr. J. F. McKellican, Burgh Surveyor of Blairgowrie.

UNTIL towards the end of 1931 the standard live load for road bridges in Great Britain was the Ministry of Transport Standard Train composed of a series of fairly uniformly distributed axle loads from trailers drawn by an engine having one axle load greatly exceeding any other in the train. If trains of this type are used in designing the girders of large bridges, the road is assumed to be loaded with as many trains as possible and the heavy axles placed in the positions where they cause the greatest stresses. The principal defects in this system of loading are the improbability of the whole of a long bridge being loaded at one time and the assumption that the allowance for impact remains unchanged as the span lengthens.

In 1931 the Ministry of Transport issued its Equivalent Loading Curve (see next page) which has much simplified this phase of bridge design, and removed some of the anomalies implied in the standard train. The uniform loads indicated by the curve are applicable to all spans, and diminish very rapidly as the loaded length increases. Likewise the impact factor falls off rapidly from 50 per cent. for 75-ft. spans and under to 15 per cent. for spans of 400 ft. and finally vanishes for very long spans. The whole live load on a given length consists of a uniformly distributed portion equal in magnitude to the ordinary axle loads of the standard train and a knife-edge load equal to the excess of the heavy-axle load of the train above the ordinary axle load. Thus the loading is neither a true equivalent uniform load—a difficult quantity to ascertain for all members of a bridge—nor a system of concentrated loads, but it is an excellent compromise between the simplest of all loads and that which agrees most closely with the loads transmitted by road vehicles and any likely increase in these.

As the experience of railway engineers has proved, it is dangerous to state that the limit of loading has been reached, but in the case of road bridges designed to meet the Ministry of Transport's requirements there is still a margin of safety, more especially as the loads specified for spans less than 10 ft. cover the cases of the two 11-ton wheels of the train spaced 1 ft. apart and a single 20-ton wheel load.

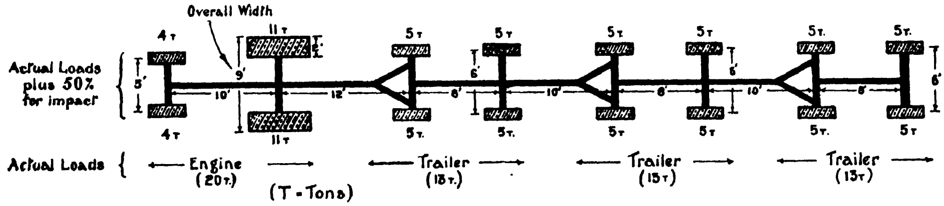
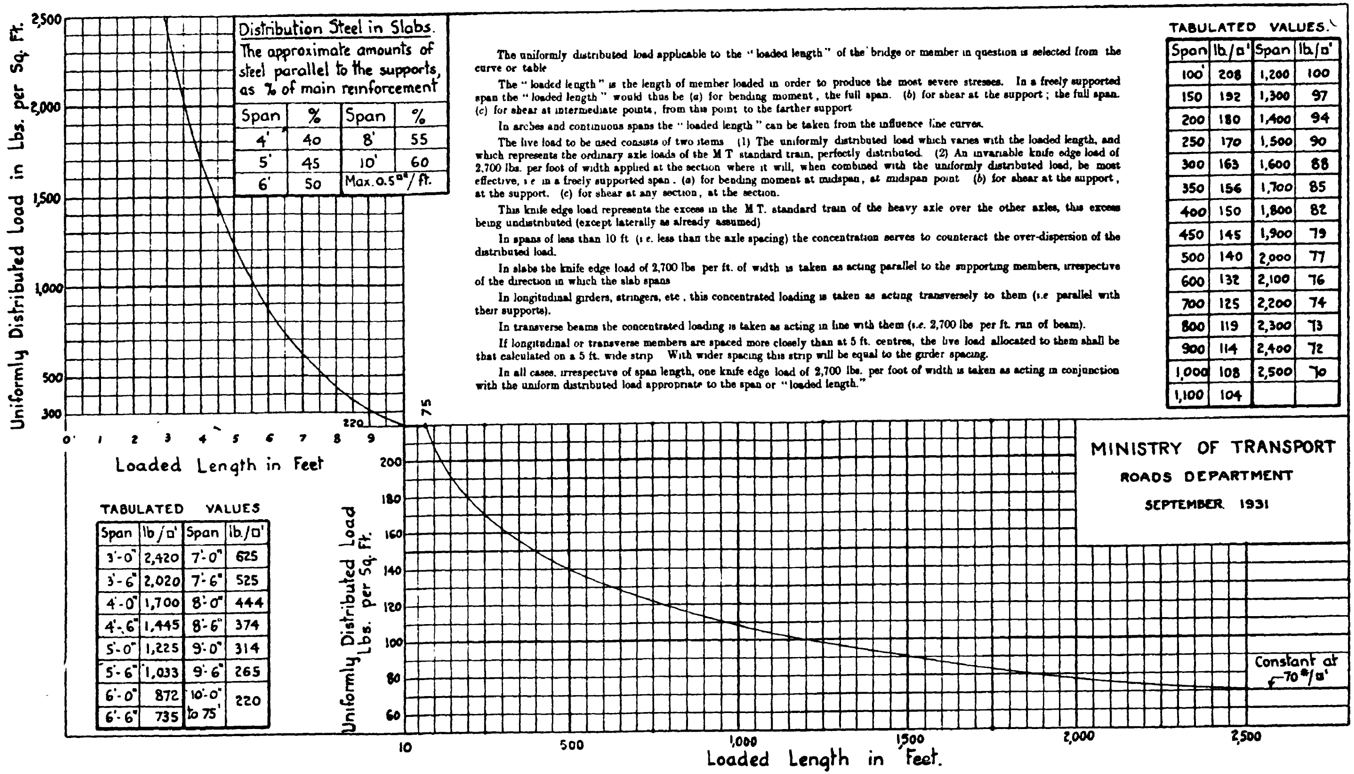


FIG. 174.—MINISTRY OF TRANSPORT STANDARD TRAIN.

STANDARD LOAD FOR HIGHWAY BRIDGES.

EQUIVALENT LOADING CURVE.



Distribution Steel in Slabs.

The approximate amounts of steel parallel to the supports, as % of main reinforcement

Span	%	Span	%
4'	40	8'	55
5'	45	10'	60
6'	50	Max. 0.5□"/ft.	

The uniformly distributed load applicable to the "loaded length" of the bridge or member in question is selected from the curve or table

The "loaded length" is the length of member loaded in order to produce the most severe stresses. In a freely supported span the "loaded length" would thus be (*a*) for bending moment, the full span. (*b*) for shear at the support; the full span. (*c*) for shear at intermediate points, from this point to the farther support

In arches and continuous spans the "loaded length" can be taken from the influence line curves.

The live load to be used consists of two items (1) The uniformly distributed load which varies with the loaded length, and which represents the ordinary axle loads of the M T standard train, perfectly distributed. (2) An invariable knife edge load of 2,700 lbs. per foot of width applied at the section where it will, when combined with the uniformly distributed load, be most effective, i e in a freely supported span. (*a*) for bending moment at midspan, at midspan point (*b*) for shear at the support, at the support. (*c*) for shear at any section, at the section.

This knife edge load represents the excess in the M T. standard train of the heavy axle over the other axles, this excess being undistributed (except laterally as already assumed)

In spans of less than 10 ft (i e. less than the axle spacing) the concentration serves to counteract the over-dispersion of the distributed load.

In slabs the knife edge load of 2,700 lbs per ft. of width is taken as acting parallel to the supporting members, irrespective of the direction in which the slab spans

In longitudinal girders, stringers, etc, this concentrated loading is taken as acting transversely to them (i.e parallel with their supports).

In transverse beams the concentrated loading is taken as acting in line with them (i.e. 2,700 lbs per ft. run of beam).

If longitudinal or transverse members are spaced more closely than at 5 ft. centres, the live load allocated to them shall be that calculated on a 5 ft. wide strip With wider spacing this strip will be equal to the girder spacing.

In all cases, irrespective of span length, one knife edge load of 2,700 lbs. per foot of width is taken as acting in conjunction with the uniform distributed load appropriate to the span or "loaded length."

TABULATED VALUES.

Span	lb./□'	Span	lb./□'
100'	208	1,200	100
150	192	1,300	97
200	180	1,400	94
250	170	1,500	90
300	163	1,600	88
350	156	1,700	85
400	150	1,800	82
450	145	1,900	79
500	140	2,000	77
600	132	2,100	76
700	125	2,200	74
800	119	2,300	73
900	114	2,400	72
1,000	108	2,500	70
1,100	104		

TABULATED VALUES

Span	lb/□'	Span	lb./□'
3'-0"	2,420	7'-0"	625
3'-6"	2,020	7'-6"	525
4'-0"	1,700	8'-0"	444
4'-6"	1,445	8'-6"	374
5'-0"	1,225	9'-0"	314
5'-6"	1,033	9'-6"	265
6'-0"	872	10'-0" to 75'	220
6'-6"	735		

MINISTRY OF TRANSPORT
ROADS DEPARTMENT
SEPTEMBER 1931

FIG. 175. (*See previous page.*)